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ICONOGRAPHIC

ENCYCLOPÆDIA

OF

SCIENCE, LITERATURE, AND ART.

SYSTEMATICALLY ARRANGED

BY

J. G. HECK.

TRANSLATED FROM THE GERMAN, WITH ADDITIONS,

AND EDITED BY

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PREFACE.

The text of the work which is now presented to the American public is based upon the well known "Bilder Atlas zum Conversations Lexicon," just published in Leipsic, by F. A. Brockhaus, and edited by Mr. John G. Heck. The engravings are impressions from the original steel plates.

The object steadily kept in view in preparing the Iconographic Encyclopædia has been to furnish a book to which the general reader may apply, for an explanation of the principal physical facts which come under his notice. To do this satisfactorily, pictorial representation is necessary, which it is hoped the five hundred quarto plates, with their 12,000 figures, will abundantly furnish.

Much of the utility of an Encyclopædia depends on its arrangement. The method which the Editor's experience of works of this kind has shown to be most convenient, is that of a systematic grouping of distinct treatises, according to their natural affinities. The work thus becomes, as it were, a series of text-books, capable of being used as such, and to which recourse may be had for all the general information required on a given subject.

To enable the reader, however, to refer readily to any individual fact a copious alphabetical index, or series of indexes, is indispensable. By including numerous cross references, it will be possible to furnish all the facilities of a strictly alphabetical arrangement, without any of its disadvantages.

This, then, is the plan which has been adopted in the arrangement of the Iconographic Encyclopædia. Each article falling within its scope has been treated of independently, and, as far as it goes, is complete in itself. It will not be expected that in the extensive range of subjects involved, even with the exclusion of Biography, Speculative Philosophy, and all abstract sciences in general, any one can be treated in its fullest extent. All that has been aimed at, and indeed all that could have been looked for, was to present a general view of each subject, essentially popular in character, and fitted, more particularly, for those who wish to have the principal facts of numerous works condensed in a single one. Nevertheless, it will be found, on examination, that many of the subdivisions of this Encyclopædia are much fuller in their details than most of the text-books or popular treatises of the day.

Tables of Contents and Indexes have been prepared for each volume, and no pains have been spared to make these more than usually accurate. The indexes do not refer to words merely, but to facts and ideas, so that the text can be readily consulted upon any given topic. The lists of the figures on the plates will be found under the contents of the text which they are intended to elucidate, with references to the pages in the letter-press where explanations may be looked for. They furnish an immediate explanation of any figure that may arrest the eye. A glossary of the German terms and phrases used in a few of the plates is also added to these lists. It would undoubtedly have been more convenient if the few plates which have caused the necessity of such translations, had been re-engraved in English; but the expense of doing so would have more than doubled the price of the work, whose unparalleled cheapness could only be secured by a liberal contract for impressions from the excellent German plates.

To Mr. Heck belongs exclusively the credit of the conception and execution of the original work; and whether we regard its magnitude, or the regularity and efficiency of its performance, it is one that has rarely, if ever, been excelled.

In undertaking an English version of the Iconographic Encyclopædia it was soon found that a literal translation of the original

would not satisfy the wants of the American public. Written in and for Germany, the different subjects were treated of much more fully in relation to that country than to the rest of the world. In some articles, too, owing to the lapse of time or other causes, certain omissions of data occurred, which did not allow of their being considered as representing the present state of science, or as suiting the wants of the United States. This, therefore, has rendered it necessary to make copious additions, alterations, and abridgments in the respective translations; while, in some instances, it has been thought proper to re-write entire articles. Several of these original papers have been prepared by the Editor, and the remainder kindly furnished by some of his friends. Some of these again have relieved him of the burden of translating, and have added much to the merit of their work by judicious alterations and additions; while others have revised his MSS. and enriched them with important suggestions. The authority and value of the assistance thus obtained will be sufficiently evident from the names of those who have so kindly rendered it. To all he here takes the opportunity of returning his warmest acknowledgments.

The second volume, or the one containing Botany, Zoology, and Anthropology, has been entirely re-written. The articles in it not prepared by the Editor are *Invertebrate Zoology*, by Prof. S. S. Haldeman; *Ornithology*, by John Cassin, Esq.; and *Mammalia*, by Charles Girard, Esq.

The friends to whom he is indebted for careful revision of his MSS. are, Prof. Wolcott Gibbs (*Chemistry*); Prof. J. D. Dana (*Mineralogy*); Prof. L. Agassiz (*Geognosy and Geology*); Dr. Asa Gray (*Botany*); Dr. T. G. Wormley (*Anatomy*); and Herman Ludewig, Esq. (*Geography*).

Those who have assisted him by translating and editing entire articles are, Wm. M. Baird, Esq. (*Ethnology of the Present Day*); Major C. H. Larned, U. S. Army (*Military and Naval Sciences*); F. A. Petersen, Esq. (*Architecture*); Prof. Chas. E. Blumenthal (*Mythology and Religious Rites*); Prof. Wm. Turner (*Fine Arts*); and Samuel Cooper, Esq. (*Technology*).

The Editor is likewise under very great obligations to the

Publisher, not only for affording him every facility in the prosecution of his task, but for unwearied and invaluable assistance in the discharge of his editorial duties. He here also takes occasion to acknowledge his indebtedness to Mr. Wm. H. Smith for revision of the proof-sheets and preparation of the Alphabetical Indexes; and also to Mr. Robert Craighead for the care which he has displayed in the typographical execution.

S. F. Baird

Washington City, D. C., April, 1851.

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GLOSSARY.

a = *der Projection des Bergstriches*, a = Projection of the mountain tract.
b = *der Höhe der horizontalen Schicht*, b = Height of the horizontal stratum.
c = *wahre Länge des Bergstriches*, c = True length of the mountain tract.

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GLOSSARY.

Abend, Evening ; — *stern*, Evening star.
Abnehmender Mond, Decreasing moon.
Aphelium, Aphelion.
Apsidenlinie, Line of Apsides.
Aufsteigender Knoten, Ascending node.
Austritt beim Aufgang der Sonne, Emersion at sunrise ; — *beim Untergang der Sonne*, Emersion at sunset.
Axe der Ekliptik, Axis of the Ecliptic.
Bahn des Merkur, Orbit of Mercury ; — *der Venus*, Orbit of Venus.

GLOSSARY—(*Continued.*)

Colur des Frühlings-Æquinoxiums, Colure of the vernal equinox ; — *des Herbst-Æquinoxiums,* Col. of the Autumnal equinox ; — *der Nachtgleichen,* Col. of the equinoxes ; — *des Sommersolstitiums,* Col. of the Summer solstice ; — *des Wintersolstitiums,* Col. of the Winter solstice.

Comet von 1811 *vor seiner Erscheinung. Projectirt auf die Ekliptik am* 25 *März* 1811. *Neigung der Bahn* 75° 5′, Comet of 1811 before its appearance. Projected on the ecliptic March 25, 1811, Inclination of the orbit 75° 5′. — *von* 1811 *nach seiner Erscheinung b. am* 1 *März* 1812, Comet of 1811 after its appearance until March 1, 1812.

Dauer der längsten Nächte, Duration of the longest nights ; — *des längsten Tages,* Duration of the longest day.

Dichteres Medium, Denser medium.

Drei Uhr Morgens, 3 o'clock A. M. ; — *Nachmittag,* 3 o'clock P. M.

Dritter Octant, Third octant.

Dünneres Medium, Rarer medium.

Ebene der Pallas, d. Juno, &c., Planes of the orbits of Pallas, Juno, &c.

Eintritt beim Aufgang der Sonne, Entrance at sunrise ; — *beim Untergang d. Sonne,* Entrance at sunset.

Ekliptik, Ecliptic.

Erdaxe, Axis of the earth.

Erdbahn, Orbit of the earth.

Erde, Earth.

Erster Octant, First octant.

Erstes Viertel, First quarter.

Excentricität, Eccentricity.

Frühling, Spring.

Frühlingsnachtgleiche, Vernal equinox.

Gemässigte Zone, Temperate zone.

Grosse Axe, Axis of the heavens.

Halley'scher Comet v. 1759 *u.* 1835, *Neigung seiner Bahn,* Halley's Comet of 1759 and 1835, inclination of its orbit.

Heisse Zone, Torrid zone.

Herbst, Autumn.

Herbstnachtgleiche, Autumnal equinox.

Horizont, Horizon.

Kalte Zone, Frigid zone.

Kometenbahn, Orbit of a comet.

Letztes Viertel, Last quarter.

Millionen Meilen, Millions of miles.

Mittag, Noon.

Mittelkraft, Mean force.

Mitternacht, Midnight.

Monate, Months.

Mond, Moon ; — *-bahn,* Orbit of the moon ; — *-finsterniss,* Eclipse of the moon.

Morgen, Morning ; — *-stern,* Morning star.

Neumond, New moon.

Neun Uhr Abends, 9 P.M. ; — *Morgens,* 9 A.M.

Niedersteigender Knoten, Descending node.

Nord, North ; — *-pol,* Northpole.

Nördliche Declination der Sonne, Northern declination of the sun.

Nördlicher Polarkreis, Arctic circle.

Obere Conjunction, Superior conjunction.

Œstliche Digression, East digression.

Ost, East.

Perihelium, Perihelion.

Polarstern, Polar star.

Polhöhe über dem Horizont, Elevation of the pole above the horizon.

GLOSSARY—(*Continued.*)

Richtung des Schattens um Mittag, Direction of the shadow at noon.

Rotationsaxe, Axis of rotation.

Scheinbarer Himmelsbogen, Apparent arch of the heavens ; — *Horizont,* visible horizon.

Sechs Uhr Abends, 6 P.M. ; — *Morgens,* 6 A.M.

Solstitial oder Wendepunktlinie, Solstitial colure.

Sommer, Summer ; — *-Sonnenwende,* Summer Solstice.

Sonne, Sun ; — *Sonnen-Æquator,* Sun's equator ; — *-finsterniss,* Eclipse of the sun ; — *-scheibe im Grössenverhältniss zu den Planeten,* The sun's disk ; its size compared to the diameters of the planets.

Stunden, Hours ; — *Entfernung,* Hours' distance ; — *-ring,* Hour-circle.

Süd, South ; — *-pol,* South pole.

Südliche Declination der Sonne, Southern declination of the sun.

Südlicher Polarkreis, Antarctic circle.

Südwestlicher Sonnenrand, Southwestern edge of the sun.

Trabanten des Jupiter ; — des Saturn ; — des Uranus, Satellites of Jupiter, Saturn, and Uranus.

Untere Conjunction, inferior conjunction.

Vierter Octant, Fourth octant.

Vollmond, Full moon.

Vom Pol bis zum Zenith, From pole to zenith ; — *Zenith biz zum Æquator,* From zenith to equator.

Wahrer Horizont, True horizon.

Wendekreis des Krebses, Tropic of Cancer ; — *des Steinbocks,* Tropic of Capricorn.

Westliche Digression, West digression.

Winter-Sonnenwende, Winter solstice.

Zoll, Digit, inch.

Zunehmender Mond, Increasing moon.

Zweites Octant, Second octant.

☞ For names of Constellations of the Zodiac, see p. 90.

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GLOSSARY.

Anfang bei Sonnenaufgang, Beginning at sunrise; — *bei Sonnenuntergang*, beginning at sunset.
Arabien, Arabia.
Atlantischer Ocean, Atlantic Ocean.
Azorische Inseln, The Azores.
Berberey, Barbary.
Berührung des Sonnen-, und Mondrandes, Contact of the edges of sun and moon.
Canarische Inseln, Canary Islands.
Capverdische Inseln, Cape Verd Islands.
Centrale oder totale Verfinsterung, Central or total eclipse.
Drei Zoll Verfinsterung, Three digits eclipsed.
Ende bei Sonnenaufgang, End at sunrise; — *bei Sonnenuntergang*, End at sunset.
Grönland, Greenland.
Grossbritanien, Great Britain.
Grosser Ocean, Pacific Ocean.
Indisches Meer, Indian Sea.
Island, Iceland,
Mittel bie Sonnenaufgang, Middle at sunrise; — *bei Sonnenuntergang*, Middle at sunset.
Mittelländisches Meer, Mediterranean Sea.
Mongolei, Mongolia.
Neun Zoll Verfinsterung Nine digits eclipsed.
Nordpol, North pole.
Norwegen, Norway.
Nubien, Nubia.
Ost Indien, East Indies.

GLOSSARY—(*Continued.*)

Russland, Russia.
Sechs Zoll Verfinsterung, Six digits eclipsed.
Sibirien, Siberia.

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GLOSSARY.

Februar, February.
Fische, Pisces.
Frühling 90 *Tage*, Spring 90 days.
Heisseste Temperatur, Hottest temperature.
Herbst 90 *Tage*, Autumn 90 days.
Januar, January.
Juli, July.
Jungfrau, Virgo.
Juni, June.
Kälteste Temperatur, Coldest temperature.
Krebs, Cancer.
Löwe, Leo.
Mai, May.
März, March.
Mittlere Temperatur, Medium temperature.
Schütze, Sagittarius.
Skorpion, Scorpio.
Sommer 93 *Tage*, Summer 93 days.
Steinbock, Capricornus.
Stier, Taurus.
Waage, Libra.
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GLOSSARY.

Ægypten, Egypt.
Æquator-Grenze des Schneefalls, Equatorial boundary of the snow region.
Aleuten, Aleutian Islands.
Arabien, Arabia.
Asien, Asia.
Barometer steigt, — fällt, Barometer rises, — falls.
Berberei, Barbary.
Beständiger Regen, Perpetual rain.
C. der guten Hoffnung, Cape of Good Hope.
Canarische Inseln, Canary Islands.
Capverdische Inseln, Cape Verd Islands.
Deutschland, Germany.
Erd-Æquator, Terrestrial equator.
Europa, Europe.
Frankreich, France.
Freundschafts Inseln, Friendly Islands.
Gebiet der Monsun Regen, Region of the Monsoons.
Gesellschafts Inseln, Society Islands.
Grönland, Greenland.
Grossbritanien, Great Britain.
Grosser Ocean, Pacific Ocean.

GLOSSARY—(*Continued.*)

Herbst und Winter Regen, Autumn and winter rains.
Indisches Meer, Indian Sea.
Italien, Italy.
Kopenhagen, Copenhagen.
Kurve von Leith, Br., Curve of Leith, latitude.
Kurve von Padua, Br., Curve of Padua, latitude.
Linie ohne Inclination, Line without inclination.
Magnetischer Æquator, Magnetic equator.
Manschurei, Mandshoo territory.
Maximum der magnet. Kraft, Maximum of magnetic power.
Mittlere Tageswärme, Medium daily temperature.
Mongolei, Mongolia.
N. O., N. E.
Neufundland, Newfoundland.
Neu Guinea, New Guinea.
Neu Sealand, New Zealand.
Niedrige Inseln, Low Islands.
Nord Amerika, North America.
Nördlicher Gürtel der beständigen Niederschläge, Northern zone of perpetual deposits.
Nördliche Hemisphäre, Northern Hemisphere.
Nördlicher Polarkreis, Arctic Circle.
Nördliches Eismeer, Arctic Sea.
Nordpol, North pole.
Nord See, North sea.
Norwegen, Norway.
Nubien, Nubia.
Oceanien, Oceania.
Ost Indien, The East Indies.
Ostseite, East side.
Persien, Persia.
Provinz des Herbstregens; — des Sommerregens; — des Winterregens, Region of autumnal, of summer, and of winter rains.
Regenloses Gebiet, Rainless region.
Russland, Russia.
Schwacher Sommerregen, Light summer rain.
Sibirien, Siberia.
S. O., S. E.
S. O. Monsun im Apr.–Oct., N. W. Monsun im Oct.–Apr., S. E. Monsoon from April to October, N. W. Monsoon from October to April.
Spanien, Spain.
Süd Amerika, South America.
Südpol, South pole.
Südlicher Continent, Southern continent.
Südlicher Gürtel der beständigen Niederschläge, Southern zone of perpetual deposits.
Südliche Hemisphäre, Southern Hemisphere.
S. W. Monsun im Apr.–Oct., N. O. Monsun im Oct.–Apr., S. W. Monsoon from April to October, N. E. Monsoon from October to April.
Thermometer steigt, — fällt, Thermometer rises, — falls.
Turkei, Turkey.
Vereinigte Staaten, United States.
Wärme-Æquator, Equator of heat.
Wendekreis des Krebses; — des Steinbocks, Tropic of Cancer; — of Capricorn.
West Indien, The West Indies.
Westseite, West side.
Winterregen, Winter rains.
Wüste Schamo oder Gobi, Desert of Shamo, or Gobi.
Zone häufiger, fast beständiger Niederschläge, stets mit electrischen Explosionen, Zone of frequent, nearly perpetual deposits, always accompanied by electrical explosions.

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GLOSSARY.

Basalt Boden, Basaltic soil.
Bugt, Bay.
Busen von Neapel, — von Salerno, Bay of Naples, — of Salerno.
Cyclopen Inseln, Cyclops Islands.
Die Flegreischen Felder, The Phlegræan fields.
Fiorden, The inlet.
Island, Iceland.
Längenthal im Trachyt, Long valley in the trachyte formation.
Lava Ströme, Lava streams.
Neapel, Naples.
Nord Cap, North Cape.
Œ, Island.
Passhöhe, Height of the pass.
Polarkreis, Arctic circle.
See, Lake.
Vesuv, Vesuvius.

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Special Geognosy.

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GLOSSARY.

Aufgeschw. Land, Deposited ground.
Braunschweig, Brunswick.
Bunter Sandstein, Variegated sandstone.
Donau, Danube.
Ebbe Geb., Ebbe Mountains.
Egge Geb., Egge Mountains.
Geb. v. Charolais, Mountains of Charolais.
Harz Gebirge, Hartz Mountains; — *und Thüringer Wald*, Hartz and Thuringian Mountains.
Hochwald, High forest (mountain tract).
Jura Gebirg, Jura Mountains; — *-kalk*, Jurassic Limestone.
Kohlengebirge, Carboniferous formation.
Kohlenkalk, Carboniferous limestone.
Kohlensandstein, Carboniferous sandstone.
Kreide, Chalk.
Laacher See, Lake Laach.
Porphyr, Porphyry.
Quadersandstein, Freestone.
Rhein, Rhine.
Rheinisches Uebergangsgebirg, Rhenish transition rock.
Rothhaar Geb., Rothhaar Mountains.
Schuttland, Conglomerate.
Steink. Gebilde, Carboniferous formation.
Tertiär, Tertiary.
Teutoburger Wald, Teutoburg forest.
Todtliegendes, Red sandstone.
Trias, Rock salt formation.
Trier, Treves.
Uebergangskalk, Transition limestone.
Vogel Geb., Vogel Mountains.

GLOSSARY—(*Continued.*)

Vogesen sandstein, Vosges sandstone.
Vulcan Gebilde; — Gerölle, Volcanic formation; — rubble.
Weser Geb., Weser Mountains.

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GLOSSARY.

Ægatische In., Ægatian Islands.
Atlantischer Ocean, Atlantic Ocean.
Canal von Malta, Maltese Channel.
Deutschland, Germany.
Frankreich, France.
Grosse Antillen, The larger West India Islands.
Indischer Ocean, Indian Ocean.
Kleine Antillen, The smaller West India Islands.
Liparische In., Liparian Islands.
Lissabon, Lisbon.
Meerb. v. Taranto, Bay of Taranto.
Mittelländisches Meer, Mediterranean Sea.
Mozambique Kanal, Mozambique Channel.
Neapel, Naples.
Nord Amerika, North America.
Sicilien, Sicily.
Spanien, Spain.
Str. von Messina, Strait of Messina.
Türkei, Turkey.
Tyrrhenisches Meer, Tyrrhenian Sea.
Venedig, Venice.
Vesuv, Vesuvius.
Wien, Vienna.

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ERRATUM.

Page 220 (Physics, p. 46). Under the head of *Velocity of Efflux* the following paragraph was omitted; it ought to be inserted after the description of Plate 17, Fig. 33.

The Swimmer of Prony (fig. 35) is an apparatus employed for obtaining a constant height of pressure of water. C is a box floating in the vessel, D, and supporting, by means of the rods A, B, a second box, G (below the aperture, E, of the vessel, D), into which all the water flowing from D is received through the funnel, F. The height of pressure in D will thereby remain unchanged, as the weight of the box, G, increased at the rate of the efflux from D, will draw down the box, C, so as to replace the water which has passed into G.

MATHEMATICS.

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MATHEMATICS is the science which treats of quantity and of the various forms and combinations of magnitudes. The idea of magnitude applies to everything which either actually or abstractly admits of increase or diminution.

Mathematics is divided into Pure and Applied. The former derives all its ideas and conclusions directly through the understanding, without requiring the least assistance from the experience and knowledge obtained through the senses, while the latter applies the deductions of the former to the various objects of experience and of the external world. Pure Mathematics distinguishes two kinds of magnitudes,—continuous, and interrupted or discrete. A magnitude is said to be continuous when its parts adhere closely together, so that the ending of one part coincides exactly with the beginning of the next; to this species belong the magnitudes of extent or space, *e. g.* a surface. A magnitude is interrupted or discrete when its parts are separated one from another, as the individual stones in a pile. Pure Mathematics is therefore divided into two principal sections, Geometry and Arithmetic (in its wider sense). Arithmetic, which includes Arithmetic proper, Algebra, and the analysis of finite and infinite quantities, offers from its very nature hardly any material for pictorial representations: we must therefore confine ourselves to geometry alone

Geometry (earth measuring) derives its name from a single application of the science, which will be treated of hereafter; and, as before remarked, has reference to continuously extended magnitudes, or magnitudes of space. As there are three different directions or dimensions of extension, so are there also three different kinds of magnitude or space,—lines, surfaces, and solids; of which lines extend only in one direction (length), surfaces in two directions (length and breadth), and solids in three (length, breadth, and height or thickness). Lines are bounded by points, surfaces by lines, and solids by surfaces. Lines are divided into straight and curved; in like manner, surfaces into plane and curved. Geometry itself, nowever, is not divided according to the three kinds of magnitudes, but only into two principal sections,—Planimetry (Plane Geometry), and Stereometry (Geometry of Solids). The former treats of such magnitudes of space or combinations of magnitudes as are found in a single plane, or in which only two dimensions occur (length and breadth); the latter, of those in which all these three are found (length, breadth, and height or thickness), and hence it refers to

solids. Geometry is again divided into the lower and higher, of which the former treats of rectilineal figures and the circle, of bodies bounded by planes, and finally of the cylinder, cone, and sphere; the latter of curved lines, of surfaces inclosed by them, and of the solids and curved surfaces which they generate.

I. PLANIMETRY OR PLANE GEOMETRY.

1. GENERAL IDEAS.

Lines, as already mentioned, are divided into straight (*pl.* 1, *fig.* 1) and curved (*fig.* 2). A broken line (*fig.* 3) cannot be said to be a particular species of line, but only a combination of several straight lines. A mixed line (*fig.* 4) is the union of straight and curved. The idea of horizontal and vertical lines (*figs.* 5, 6) is essentially foreign to pure Geometry. In applied or practical Geometry we call a line horizontal, when it runs in the same direction with the plane of the horizon, or the surface of still water, sometimes termed level; and vertical or perpendicular, when it corresponds to the direction of the plumb-line, or that of a string to which hangs a freely suspended weight; every other straight line is called slanting or oblique (*fig.* 7). Two straight lines in the same plane are said to be *parallel* (*fig.* 8) when they never meet however far they may be produced, or when they are everywhere equally distant from each other. Curved lines also, if they possess the latter property, are sometimes called parallel, although this extension of the idea is hardly allowable.

Two straight lines, when they meet in a point (*fig.* 9), form an angle with each other: this is the name which is given to their inclination or separation. The lines are called the sides, and the point where they meet the vertex. Any angle, even if it has both sides curved (*fig.* 10), or one side curved and the other straight (*fig.* 11), may still be reduced to a rectilineal angle. In elementary Geometry, all angles are rectilineal. If one of the sides of an angle is extended beyond the vertex, a second angle is formed, which is called the adjacent angle of the first. If the two adjacent angles are equal (*fig.* 7), each is called a *right* angle (also *fig.* 12). All right angles are equal; and on that account they are used as a standard by which to measure other angles. Every angle smaller than a right angle is called acute (*fig.* 13), and every angle that is larger is called obtuse (*fig.* 14). Two or more angles that have a common vertex, and lie on the same side of a straight line in such a manner that this line constitutes one side of the first angle and one of the last, are altogether equal to two right angles. The angles about a point are together equal to four right angles.

A flat space bounded by lines is called a *figure*. A figure is called *rectilineal* if it is bounded by straight lines; if by curved lines, *curvilineal;* and it is a *mixed figure* when it is inclosed by both straight and curved lines. Plane Geometry deals only with plane figures (figures that lie in a plane

surface). If a rectilineal figure is bounded by three lines, it is called a *triangle;* if by four, a *quadrilateral;* if by more than four, a *polygon.*

Triangles are divided, *first,* according to their sides, into *equilateral* (*pl.* 1, *fig.* 15), in which all the sides are equal; *isosceles* (*fig.* 16), which have only two sides equal; and *scalene* (*fig.* 17), in which all the sides are unequal. *Secondly,* they are divided with reference to their angles, into *right angled triangles* (*fig.* 18), when they have one angle right and two acute; *obtuse angled triangles* (*fig.* 20), when they have one angle obtuse and two acute; and *acute angled triangles* (*fig.* 19), when all the angles are acute. That side of a right angled triangle which is opposite to the right angle is called the hypothenuse, the two others are called the legs.

Among quadrangular figures, the parallelograms form a remarkable class. They are quadrilaterals in which the two opposite sides are equal and parallel. Every parallelogram is divided by a diagonal—a straight line joining the vertices of two opposite angles—into two equal triangles (*fig.* 23). There are four different kinds of parallelograms: the *square* (*fig.* 21), in which all the sides are equal, and all the angles right angles; the *rectangle* (*fig.* 22), which has also its angles right angles, and only its parallel sides equal; the *rhombus* or *lozenge* (*fig.* 24), in which all the sides are equal, but only its opposite angles equal; and the *rhomboid* (*fig.* 25), which has only its opposite sides and angles equal. A quadrilateral in which only two sides are parallel is called a *trapezoid* (*fig.* 27). It is called a right angled trapezoid when it has two right angles (*fig.* 26), and equilateral when the two sides that are not parallel are equal (*fig.* 28). A trapezoid may have three sides equal, but the parallel sides must always be unequal. A quadrilateral in which none of the sides are parallel is called a *trapezium* (*fig.* 29).

A polygon is called regular when all its sides and angles are equal, and irregular when this is not the case. *Figs.* 30–37 represent regular polygons, viz. *fig.* 30, a 5-sided figure, or *pentagon; fig.* 31, a 6-sided, or *hexagon; fig.* 32, a 7-sided figure, or *heptagon; fig.* 33, an 8-sided, or *octagon; fig.* 34, a 9-sided figure, or *nonagon; fig.* 35, a 10-sided, or *decagon; fig.* 36, one of 11 sides, or *undecagon; fig.* 37, one of 12, or *dodecagon;* all of which are accompanied by circles, either circumscribed or inscribed.

The only curved line which occurs in elementary geometry, is the circular. The extremities of this line meet, and every point in it is equally distant from a point in the space inclosed, called the centre. The surface inclosed by the circular line is called the circle (*fig.* 38). In its relation to this, the circular line is called the circumference or periphery. A portion of the circular line is called an *arc,* e. g. *abc* (*fig.* 39). The size of an arc with reference to the whole circumference is measured by degrees. Every circle is divided into 360 equal parts, which are called degrees; each degree contains 60 minutes, and each minute 60 seconds. A straight line, drawn from the centre of a circle to its circumference, is called a *semi-diameter* or *radius,* e. g. *cd* (*fig.* 40); a straight line uniting two points of the circumference, a *chord,* e. g. *ef* (*fig.* 40, also *fig.* 43); and a *diameter* when, passing through the centre, it unites two opposite points of the

circumference, as *ab* (*pl.* 1, *fig.* 40). Every chord cuts from a circle a *segment*, as *bac* (*fig.* 41). The part of a circle included between two radii and an arc is called a *sector* (*fig.* 42). The angle formed by two radii is called a centre angle, as *bac* (*fig.* 42). An angle formed by two chords meeting in the line of the circumference, is called an inscribed angle (*fig.* 44). When a straight line, produced at pleasure, touches a circumference only at one point, it is called a tangent, e. g. *bc* (*fig.* 46); any such straight line, however, which either immediately or when produced cuts the circumference in two points, is called a secant, *ab* (*fig.* 46). A rectilineal figure is said to be inscribed in a circle when all its sides are chords (*fig.* 45); it is said to be circumscribed about a circle when all its sides are tangents (*fig.* 54). Two or more circles are said to be *concentric* when they have a common centre (*fig.* 47); circles of different centres are excentric. Two excentric circles touch one another when their circumferences have only one point in common: this point may be either on the exterior (*fig.* 53) or on the interior of the circumference. In the first case the sum, in the second the difference of their radii, will be the distance between their centres; in both cases the centres and the point of tangency will be in the same straight line. Two excentric circles cut each other (*fig.* 48) when their circumferences have two points in common. Each point of intersection forms a triangle with the two centres.

2. OF THE POSITION OF STRAIGHT LINES IN THE SAME PLANE.

Only one straight line can be drawn between two given points, so that the position and direction of a line is completely determined by these points. On the other hand, innumerable curved lines are possible between two points. A straight line is the shortest distance between two given points. Hence it follows that in a triangle each of the sides is less than the sum, but greater than the difference of the two others. If two triangles have the same base, so that the one lies entirely within the other, the outer has a greater perimeter than the inner (*pl.* 3, *fig.* 82). Two straight lines on one plane may intersect each other, either directly or when produced; they can, however, have but one point in common, or they may never meet even when produced. In the first case, they converge and form an angle; in the second, they are parallel. If two lines, whether parallel or not, as *kl*, *mn*, or *op*, *qr* (*fig.* 1), are intersected by a third straight line, *st*, then there will be eight angles formed,—four internal and four external: of these, the two internal or two external angles which lie on opposite sides of the secant line, and are not adjacent to each other, are called *alternate* angles, as *a* and *h*, *c* and *f*, *i* and *u*, *m* and *n*. Then again, two angles, one internal and the other external, lying on the same side of the secant without being adjoining, are called *opposite* angles; e. g. *a* and *i*, *c* and *g*, *k* and *o*, *m* and *n*. When parallel lines are intersected by a third straight line, each two of the alternate angles, as well as of the opposite, are equal to each other. In every triangle, the sum of all the angles is equal to two right angles. The angles

of a quadrilateral are together equal to four right angles, as will become evident if we divide the quadrilateral by a diagonal into two triangles (*pl.* 1, *fig.* 23). The sum of the angles in a pentagon is equal to six right angles, since two diagonals divide it into three triangles (*pl.* 3, *fig.* 4). And in general, the sum of the angles of a rectilineal figure is always equal to twice as many right angles, less 4, as the figure has sides. This proposition will become clearer if we draw, from a given point within the figure, lines to all its corners (*fig.* 5), and remember that the sum of all angles that have their vertex in one common point, is equal to four right angles. This proposition also holds good if the figure have a re-entrant angle (*fig.* 6); but in order to prove it in that case, it will be better to divide the figure by diagonals that must not intersect one another, into triangles, of which there will always be two less than the figure has sides.

3. OF THE EQUALITY OF FIGURES.

Two figures are said to be equal when they can be so applied to each other as to coincide throughout. The sides and angles of a figure are in such intimate and dependent relation, that from the equality of some of them we may infer the equality of the rest. For example, if of two triangles we know that three parts are mutually equal—either the three sides, or two sides and the included angle, or two sides and the angle which is opposite the greater of the two, or two angles and the included side—then may we conclude from this that the rest of the parts are also equal each to each, and that the triangles themselves are equal (*pl.* 3, *figs.* 11, 12). But of the three parts ascertained, one must always be a side, since two triangles of unequal sides may have equal angles, as in *fig.* 7. If, in this triangle *ade*, we add to *de* the parallel *bc*, then it is plain that the triangles *abc* and *ade* have their angles equal, since $q = q$, $m = n$, $o = p$; but the triangles themselves are by no means equal, since the one is only a part of the other. From these cases of equality it follows also what parts are necessary to construct a triangle. This is most easily done by having the three sides, *a*, *b*, *c*, given (*fig.* 8); but we may also employ two sides, *a*, *b*, and the included angle *m* (*fig.* 9), as well as two angles, *m*, *n*, and the included side *a* (*fig.* 10); or finally, two sides, *a*, *b*, and the angle *m* (*fig.* 18) lying opposite to one of them. It is to be observed, however, that when this angle lies opposite to the smaller of the two sides, two different triangles may be constructed, both of which will answer the conditions of the proposition, so that in this case the triangle is not completely defined. By means of the equality of triangles the following, among other properties, may also be proved: 1. In an isosceles triangle, the angles opposite the equal sides are also equal (*fig.* 13), for let $ab = ac$, and from *a* draw a line which bisects *bc*, then there will be two equal triangles in which $\angle m = \angle n$, from which it follows that $o = p$, and $q = r$, which shows that the line is perpendicular to *bc*, and bisects the angle at *a*. In an equilateral triangle, all the three angles are equal. 2. The greater angle of a triangle lies opposite to

the greater side, and vice versâ. If, in the triangle *abc*, (*fig.* 14), *ab* is greater than *ac*, then is also ∠ *acb* greater than ∠ *abc*, &c. 3. If two triangles have two sides of the one equal to two sides of the other, each to each, and the included angle unequal, the third sides will be unequal, and the greater side will belong to the greater triangle, which has the greater included angle ; or if an angle of a triangle is increased, while its including sides remain the same, then will the side opposite the angle be also increased (*figs.* 15–17).

A quadrilateral is a parallelogram, when it can be proved,—1, that two of its opposite sides are equal and parallel ; or 2, that all the opposite sides are equal ; or 3, that all the opposite sides are parallel. The opposite angles of a parallelogram are also equal : two adjacent angles form together two right angles (*fig.* 22).

Hence all the angles in a parallelogram are either right angles or two are acute and two obtuse (rhombus and rhomboid). The two diagonals of a parallelogram mutually bisect each other (*fig.* 19).

To construct a parallelogram it is generally necessary to have two sides and an angle given. For a rectangle, however, two sides are sufficient ; for a rhombus, one side and an angle ; and for a square, one side. A trapezoid can be constructed by means of its four sides (*pl.* 3, *fig.* 21), by constructing first a triangle out of the two sides *ad*, *ae*, which are not parallel, and the difference of the parallel sides *de*, then producing *de* to *c*, so that *ce* may become equal to the lesser parallel, and with *aec*, the parallelogram *abce* will be completed. A trapezium may be constructed,—1, with four sides and an angle ; 2, with three sides and the two included angles ; 3, with three sides and the angles lying about the unknown side ; 4, with two adjacent or two opposite sides and the three angles (*figs.* 23, 24).

Every regular polygon has a central point which is at an equal distance from all its sides and from all its angles. This point is found by bisecting two angles, for the bisecting lines always meet in that common centre (*fig.* 25).

The preceding propositions concerning the equality of triangles, enable us to solve and prove the solution of a number of problems of easier construction. Among these are : 1. to construct a triangle equal to a given triangle (*fig.* 26). 2. To describe a given angle *m*, on a given straight line *ab*, at a given point *a* (*fig.* 27). 3. Through a given point, to draw a line parallel to a given line. 4. To bisect a given angle (*pl.* 2, *fig.* 77). 5. To bisect a given line (*fig.* 75). 6. To draw a perpendicular to a line at a given point. 7. From a given point out of a line, to let fall a perpendicular on that line (*pl.* 3, *fig.* 28, and *pl.* 2, *fig.* 75). 8. To draw a perpendicular at the extremity of a given line (*pl.* 3, *fig.* 29, and *pl.* 2, *fig.* 76). 9. To draw a given line between the sides of a given angle *bac*, so that it may form a given angle *m* with one of the two sides (*pl.* 3, *fig.* 30). 10. To construct a triangle with a given line *a*, and two given angles *m* and *n* [the sum of which must be less than two right angles], (*fig.* 31). 11. To construct an equilateral triangle upon a given base (*pl.* 2, *fig.* 78). 12. To construct a square upon a given base *ab* (*pl.* 2, *figs.* 79, 80). In order

to obtain a regular octagon from a square, we must proceed as follows:— Draw (*pl.* 3, *fig.* 32) the two diagonals of the quadrilateral intersecting at *e*; bisect the angle *ced*; make the bisecting line $ef = ce$ or *de*, and draw *cf* and *df*; finally, describe upon the remaining three sides of the quadrilateral, equilateral triangles, which are equal to the triangle *cdf*.

4. OF THE SIMILARITY OF FIGURES.

Two figures are called *similar* when they agree in their form, or more definitely, when the angles of the one are equal to the angles of the other each to each in the same order, and the sides of the one are in the same proportion as those of the other. We arrive at the latter definition as respects triangles, by examining two lines not parallel to each other, which are intersected by several parallel lines. If we divide one of the two lines *aq*, *ar* (*pl.* 3, *fig.* 33), into the equal parts, $ab = bc = cd = de$, commencing at the point of intersection, and then draw from the points of division, *b*, *c*, *d*, *e*, parallel lines, then the divisions of the other lines thus formed will also be equal to each other. If, again, we take in one of the two lines *aq*, *ar* (*fig.* 34), two or more unequal parts, beginning at the point of intersection *a*, and then draw parallel lines from the points of division *b*, *c*, then will the resulting sections, *ad*, *de*, of the other line, be in the same proportion to one another as the sections, *ab*, *bc*. In this case the triangles *abd*, *ace*, are similar; we readily perceive that their angles are equal, and that two sides of the one triangle are always in the same proportion as the corresponding and similarly placed sides of the other. To be certain that two given triangles, *abc*, *def* (*fig.* 35), are similar, it is only necessary to know,—1, that two angles, or 2, that one angle and the ratios of the including sides, or 3, that the ratios of two of the sides and the angles opposite to the greater of them, or 4, that two ratios of sides, are equal.

The following propositions, among many others, may be proved by means of the similarity of triangles. If in a triangle *abc* (*pl.* 3, *fig.* 36), lines be drawn from two angles, *a*, *b*, to the middle of the opposite sides, each of these lines cuts the other into two parts, of which the one lying towards the bisected side is half of the other. From this it readily follows that all the three lines drawn from the angles of a triangle to the middle of the opposite sides, pass through one and the same point. If we bisect the angle *a* of the triangle *abc* (*pl.* 3, *fig.* 37), it may be readily shown that the segments into which the opposite side *bc* is divided by the bisecting line, are in the same proportion as the two other undivided sides, thus, $bd : ed :: ab : ac$. Hence we deduce the proposition, that lines bisecting the three angles of a triangle cut each other in one and the same point, which is of importance, as being the centre of the circle inscribed in the triangle. To cut off from a given triangle a smaller one similar to it, we may either, 1, draw a line parallel to one side of the triangle, or 2, from one angle of the triangle, not the least, cut off by a line another angle equal to a smaller one of the same triangle. E. g., if in *fig.* 38 the angle $n = m$, then

will the triangle *acd* be similar to *abc*. And if the second triangle, *abd* thus formed, is also to be similar to the original triangle, then must $q = o$, also $n + q$ or $bac = m + o$, which is only possible when *bac* is a right angle. In this case the bisecting line *ad* is perpendicular to *bc*. If, therefore, in a right angled triangle, we let fall a perpendicular from the vertex of the right angle upon the hypothenuse, the perpendicular thus let fall will divide the triangle into two smaller ones, similar to each other and to the original triangle (*fig.* 39–41). From this may be easily deduced, 1, that the perpendicular let fall from the vertex of the right angle, is a mean proportional between two segments of the hypothenuse; 2, that either side about the right angle is a mean proportional between the whole hypothenuse and adjacent segments. From the latter proposition follows another: that when the sides of a right angled triangle are expressed in numbers, the square of the hypothenuse will be equal to the sum of the squares of the other two sides.

With respect to the similarity of such rectilineal figures as have more than three sides, we will confine ourselves here to the following proposition: two figures are similar, when they can be divided by similarly situated diagonals into triangles which are similar each to each (*pl.* 3, *fig.* 42).

Similarity of figures may also be applied to the solution of numerous problems of construction, of which we will here mention only one;—to find a fourth proportional to the three given lines, *a*, *b*, *c* (*fig.* 43). This is a problem of the same importance in Geometry as the Rule of Three is in Arithmetic.

5. OF THE EQUIVALENCE OF AREAS IN FIGURES.

Figures are said to be equivalent when they occupy equal areas. In equality we combine similarity with equivalence. We must here premise that in triangles and parallelograms, some one side is assumed as the ground line or basis upon which the figure is supposed to rest, and that then the height or altitude is the perpendicular distance from this basis to the opposite side or angle.

Two parallelograms are equivalent, when their bases and altitudes are equal (*pl.* 3, *fig.* 45–47). Here we may always consider them as erected upon the same base, and the opposite sides will then be in one and the same parallel; in which case, apart from the condition of equality or complete coincidence, three conditions, as represented in *figs.* 45, 46, 47, are possible. A triangle is always the half of a parallelogram of the same base and altitude, therefore equal to a parallelogram of the same altitude and half the base, or to one of an equal base and half the altitude; whence it follows that triangles of equal bases and altitudes are equivalent (*fig.* 48). If we assume in succession two different sides of the same triangle as bases, they will be inversely proportional to their corresponding altitudes, viz. $ab : ac :: bc : cd$ (*fig.* 49). A trapezoid may be divided by a diagonal into two triangles, which will have the parallel sides of the trapezoid for their bases, and the perpendicular distance between these sides for their common alti-

tude; it is, therefore, equal to a parallelogram whose base is equal to half the sum of the parallel sides, and whose altitude is equal to their perpendicular distance from each other (*fig.* 50). A rhombus, whose diagonals are perpendicular to each other, will be four times as large as a right angled triangle, which has for its two legs half the diagonals of the rhombus (*fig.* 51). The areas of two parallelograms as well as of two triangles of the same base, are to each other as their altitudes; of the same altitude, as their bases; and generally, parallelograms are to each other as the products of their bases by their altitudes. The areas of two squares are to each other as the squares of their sides. The areas of two similar triangles are to one another as the squares of their homologous or similarly situated sides (*fig.* 53); the same is true generally with regard to the areas of two similar figures. If on the three sides of a right angled triangle, three similar figures, triangles or any others, be constructed, the figure on the hypothenuse will be equivalent to the sum of those on the two legs (*pl.* 3, *fig.* 54). A particular case of this proposition is known as the Pythagorean: the square described upon the hypothenuse is equivalent to the sum of the squares described on the other two sides.

As the unit of measure for the determination of the superficial relations of figures, we use a square whose side is equal to the unit of length, which, therefore, according to the length of the side, is called a square foot, a square inch, &c. To ascertain how many times one square is contained in another, it is necessary to find out how many times the side of the one is contained in that of the other, and the number thus obtained multiplied by itself; hence a square foot contains not 10 or 12 square inches, but 100 or 144, according to the number of inches, 10 or 12, into which the foot is divided, &c. The area of a square may thus be found, by measuring one of its sides and then multiplying the number expressing its length by itself. Hence we are accustomed to call the product of a number by itself, or the second power, its square. The area of a parallelogram is found by multiplying the base by the altitude (expressed in the same unit of measure); that of a triangle by multiplying the base by half the height, or the height by half the base; that of a trapezoid by multiplying half the sum of the parallel sides by their perpendicular distance; that of a regular polygon by multiplying its circumference or perimeter by half the perpendicular let fall from the centre on one of the sides; that of an irregular polygon by dividing it by diagonals into triangles, whose areas must be separately ascertained and added together.

By the assistance of the preceding propositions, many problems relative to the changing and dividing of figures may be solved. A few of these problems are the following:—1. To change a triangle into a parallelogram of equal area, or the contrary (*fig.* 55). 2. To change the triangle *abc* into another of equal area, and with a given side *be* (*fig.* 56). 3. To change a parallelogram into a rhombus of a given side *cf* (*fig.* 57), or of a given angle *m* (*fig.* 58). 4. To change a given triangle *abc* into an equilateral triangle (*fig.* 59). 5. To change a quadrilateral *abcd* into a triangle (*fig.* 60). 6. To change a given figure into another of a prescribed

shape, e. g. the triangle *abc* (*fig.* 61) into a quadrilateral similar to the given quadrilateral *defg*. 7. To divide a triangle into a certain number of equal parts by lines proceeding from one angle. 8. To cut off from a triangle a certain portion, as for instance a third, by means of a line which is to proceed from a given point, *d*, in one of its sides (*fig.* 62). 9. To cut off from a triangle, *abc*, a certain part, as a third, by lines proceeding from a given point, *d*, within the triangle (*fig.* 63). 10. From a triangle, *abc*, to cut off a certain portion, by a line parallel to one of the sides (*fig.* 64). 11. To divide a parallelogram into a given number of equal parts, by lines parallel to one of its sides. 12. From an acute angled parallelogram to cut off a given part by a line perpendicular to two of the sides (*pl.* 3, *fig.* 65). 13. To divide a parallelogram, *abcd*, into a certain number of equal parts, by lines proceeding from a given point in one of the sides (*fig.* 66). 14. From a trapezoid, *abcd*, to cut off a given part, for instance the half, by a line parallel to its parallel sides (*fig.* 67). 15. To cut off from any quadrilateral, *abcd*, a given part, by a line proceeding from a corner, *a*, or from a given point, *e*, in one of its sides (*figs.* 68, 69).

6. OF THE CIRCLE AND ITS MEASUREMENT.

A circular line cannot have more than two points in common with a straight line (*fig.* 70). A straight line intersects or touches the circle, according as it has two points in common with the circumference, or only one; in either case we must consider the line as indefinitely produced in either direction. We obtain a tangent, when we draw a perpendicular to the extremity of a radius or diameter (*fig.* 71). On the other hand, a radius drawn to the point of tangency of a tangent, will be perpendicular to it; whence it follows, that to any point of a circumference only one tangent can be drawn. Lines drawn from the same point, tangent to a circumference, are equal to each other, e. g. $su = sv$ in *fig.* 72.

Equal angles at the centre of the same circle, or of equal circles, have equal chords and areas, and the reverse. An angle at the centre is measured by the number of degrees contained by its arc. An inscribed angle is half the angle at the centre of the same arc, and is therefore measured by the half of its arc. An angle formed by a tangent and a chord is measured by half the arc included between the tangent and the chord (*fig.* 73). Inscribed angles resting upon the same or upon similar arcs are equal (*fig.* 75). When two chords intersect each other, either within the circle, or when produced, without it, the angle thus formed is measured in the first case by half the sum, and in the second by half the difference of the two arcs included between the chords (*fig.* 74). Every angle inscribed in a semicircle is a right angle (*fig.* 77). If at any given point of a diameter a perpendicular be drawn to the circumference, it will be a mean proportional to the two segments of the diameter (*fig.* 78).

From the preceding propositions may be obtained the solution of the following problems: 1. To find the centre of a circle or of a circular arc

(*pl.* 2, *fig.* 84). 2. To bisect a circular arc. 3. To draw a tangent to a given point in a circumference (*pl.* 2, *fig.* 85). 4. From a given point out of a circle, to draw a tangent to the circle (*pl.* 3, *fig.* 80). 5. Upon a given base, *ab*, to construct a triangle in which the angle opposite the base is equal to the given angle *m* (*fig.* 76). This problem is indefinite, since every point of an arc may be taken as the vertex of the triangle; but it becomes definite if the height of the triangle is also given. A particular case is exhibited in the problem: upon a given line, as hypothenuse, to construct a right angled triangle. 6. To construct a mean proportional to two given lines. 7. To divide a given triangle, *abc*, by lines running parallel to a given side, into a certain number of of parts, five for instance, that shall be either equal, or in a definite proportion (*fig.* 79).

The construction of regular polygons in and about the circle, is of importance in understanding its theory. A regular polygon is said to be inscribed in the circle, when all its sides are chords; and circumscribed about the circle, when all its sides are tangents. A regular polygon is inscribed in a circle, by dividing the circumference of the latter into as many equal parts as the polygon is to have sides, and connecting these points by chords. The difficulty here lies only in dividing the circumference into a given number of equal parts. The division into four or six parts is most easily made; the former, by drawing two diameters perpendicular to each other; the latter, by using as chords, lines equal to the radius (*fig.* 81). To divide the circumference into ten equal parts, we draw two radii perpendicular to each other, bisect the one, and connect the point of bisection with the extremity of the other, and then cut off from this connecting line a section equal to the half of the radius; the remainder will be the length of a chord whose arc is the tenth part of the circumference, or the side of a regular inscribed decagon. *Pl.* 2, *fig.* 81, shows the construction of a regular pentagon in a circle. *AB* is here a diameter, *CD* a radius perpendicular to it; from *F* the middle point of *BC*, with a radius equal to *FD*, we describe an arc intersecting *AC* in *G*; draw *DG*; this will be the side of the regular pentagon (*CG* will be the side of the regular decagon). We may obtain a pentagon by connecting the alternate angles of a decagon. From the division into four equal parts, we may readily obtain that into 8, 16, 32, &c., and the division into 10, 20, 40, 80, &c. The fifteenth part of the circumference is found by subtracting the 10th part from the 6th, for $\frac{1}{6} - \frac{1}{10} = \frac{4}{60} = \frac{1}{15}$.

A regular polygon is circumscribed about a circle, by dividing the circumference into as many equal parts as the polygon is to have sides, and then drawing tangents to all the points of division. From a polygon of any given number of sides inscribed in the circle, we may obtain a regular polygon of double the number of sides, by bisecting the arcs, whose chords form the sides of the former, and drawing chords to the half-arcs. The circumference (as well as the area) of a circle is always greater than the perimeter (or area) of an inscribed polygon, but is less than the perimeter (or area) of one circumscribed about it (*pl.* 3, *fig.* 83).

The circumference of a circle cannot be directly measured, since it is not a straight line; but if two polygons of a great number of sides be

described in and around it, and their circumferences determined, that of the circle will be intermediate. In this way Archimedes determined the ratio of the diameter to the circumference as 7 : 22, and Ludolph, as 1 : 3 14159. The latter number is employed and indicated by π, as the ratio to a diameter of 1 (or unity). Accordingly, since circles are to each other as their diameters, the circumference of any circle may be found by multiplying its diameter by π (= 3.1415926).

Every circle may be regarded as a regular polygon of an infinite number of sides; hence, also, as a triangle whose base is equal to the circumference of the circle, and whose altitude is the radius. We consequently obtain the area of a circle by multiplying the circumference by half the radius, or according to the preceding proposition, by multiplying the second power of radius by π. A sector is equal to a triangle whose base is the length of the arc, and whose altitude is equal to the radius (*pl.* 3, *fig.* 84).

Allied to the circle are the symmetrically curved lines, the oval and the ovate: each one consisting of four elongated quadrants. In the former the quadrants are all equal; in the latter only the two lying on the same side of the short axis. The following are some constructions of ovals. In *pl.* 2, *fig.* 87, an isosceles triangle, *CDE*, is constructed upon the base *CD*, and under it another and equal arc, *CDF*. From *C* and *D*, with any radius, $CA = DB$, describe arcs intersecting the equal sides produced of each triangle in *G* and *I*, *H* and *K*: and finally, connect these points by arcs described with the radii $FH = EK$, from *F* and *E* as centres. *Fig.* 88 agrees with the preceding construction, except in that the two equal triangles employed, are equilateral. In *fig.* 88, the length of the oval, or of the major axis, *AB*, is given. Divide it at *C* and *D*, into three equal parts. From the points *C* and *D*, with radii equal to $\frac{1}{3}$ *AB*, describe circles intersecting in *E* and *F*. From these points draw two diameters in each circle, *GF*, *EI*, *FH*, *EK*, and with one of these diameters as radius, from the points *E* and *F*, describe the arcs *IK* and *GH*, completing the outline. In this construction the breadth of the oval is a little more than $\frac{3}{4}$ of the length. An oval of less breadth, with the same length, *AB*, may be thus obtained (*fig.* 89). Divide *AB* into four equal parts, and from the points of division, *C*, *D*, *E*, with a radius equal to $\frac{1}{4}$ of *AB*, describe three circles, intersecting each other in *F*, *G*, *H*, and *I*. Through these points draw in the first and third circles the diameters *MH*, *NI*, *FK*, and *GL*, prolonging them until they intersect in *O* and *P*. From *O* and *P*, with radii $OK = PM$, describe the arcs *KL* and *MN*. In this construction the breadth of the oval is not quite $\frac{2}{3}$ the length. In *fig.* 91, a half-oval of given length, *AB*, is constructed in the following manner. From the points *A* and *B*, in the line *AB*, any part, $AH = BK$, is taken, and with this distance as radius, arcs are described cutting each other in *I* and *L*; with the distance between *I* and *L* as radius, describe, from these points as centres, arcs cutting each other beneath *AB*; finally, from *D* as centre, complete the circle by the arc *IL*.

II. STEREOMETRY, OR THE GEOMETRY OF SOLIDS.

1. OF THE POSITION OF LINES AND PLANES IN SPACE.

Through one or two points, as well as through one straight line, innumerable planes may pass. Only one, however, can pass through three points not in the same straight line, through two parallel or intersecting straight lines, or through a straight line and a point external to it. Two planes meeting each other without coinciding, form a straight line by their intersection. A straight line not in a plane, can have only one point in common with it. It is perpendicular to the plane when it is perpendicular to all straight lines drawn through its foot in the plane; this is likewise the case when it forms a right angle with two lines lying in the plane (*pl.* 3, *figs.* 86, 87). The angle of inclination of a line to a plane not perpendicular to it, is found by letting fall a perpendicular from any point of the line upon the plane, and connecting the extremities of the two lines by a line situated in the plane. This is the least angle which the straight line can make with lines drawn through its foot on the plane. Two straight lines perpendicular to the same plane, are parallel to each other (*fig.* 90). If, of two parallels, one stands perpendicular to a plane, the other must also. A straight line is parallel to a plane, as well as a plane parallel to a straight line, when they will not meet if produced. If a straight line be parallel to a plane, and we pass through the line, planes cutting the first plane, the lines of intersection will be parallel to each other and to the plane (*fig.* 88). Two planes perpendicular to the same straight line are parallel to each other (*fig.* 90). Two parallel planes, intersected by a third, will have the lines of intersection parallel (*fig.* 91). If two straight lines in space be intersected by three parallel planes, the segments of the one will be proportional to those of the other (*fig.* 93). Parallels or perpendiculars between two parallel planes are equal; hence the distance between two parallel planes is measured by a perpendicular let fall from one upon the other. Two angles which have three sides parallel are equal; if they lie in different planes, these latter are parallel (*fig.* 92). The inclination or separation of two planes not parallel, is measured by the angle formed by lines in each plane, drawn perpendicular to a point in the line of intersection of the planes. Planes, like lines, may form adjacent and opposite or vertical angles, which, with respect to their magnitudes, have the same properties as those of lines (*fig.* 89). Two planes are perpendicular when their angle is a right angle. If a plane be perpendicular to two intersecting planes, it will also be perpendicular to their line of intersection. If a straight line be perpendicular to a plane, every plane passing through the former will be perpendicular to the latter. When three or more planes meet in one point, they form a corner or solid angle (*pl.* 3, *fig.* 94). The edges or lines of intersection of planes meeting in this manner, form as many plane angles as there are planes. If the solid angle be formed by

three planes, then is the sum of any two of the plane angles greater than the third. In any case, however, the sum of any number of plane angles, forming a solid angle, is less than four right angles.

2. OF ANGULAR SOLIDS.

A solid may be inclosed either by plane surfaces alone, in which case it is called a polyhedron, or by curved surfaces alone, or by both plane and curved at the same time. Bodies of the first and third kind have a base, that is, a plane surface upon which the solid is supposed to rest. If such a body should have another plane bounding surface parallel to this base (in which case this plane may be considered another base), or a vertex opposite to the base, the distance between the two surfaces, or between the vertex and the base (in both cases measured by a perpendicular let fall), is called the altitude of the solid. The planes bounding a polyhedron are called its faces; their intersections, its edges. No polyhedron can have less than four faces, four solid angles, or six edges. Furthermore, no polyhedron can be inclosed by figures of six or more sides, or have equal solid angles formed by six or more plane angles.

Two solids are said to be equivalent when the spaces inclosed between their bounding surfaces are equivalent; they are equal when they agree exactly in shape and size, so that the one may be taken for the other.

A polyhedron is called regular when it is inclosed by perfectly regular and equal figures, and has all its angles equal. There are only five regular solids; 1, *tetrahedrons*, bounded by four triangles (*pl.* 2, *fig.* 56); 2, *octohedrons*, by eight (*fig.* 58); 3, *icosahedrons*, by twenty (*fig.* 60); 4, *hexahedrons*, bounded by six squares (*fig.* 57); 5, *dodecahedrons*, by twelve pentagons (*fig.* 59). The expansion of some of these solids, or the representation of their surfaces as spread out in a plane, may be found in *pl.* 4, where *fig.* 49 is the expansion of the tetrahedron, *fig.* 50 that of the hexahedron, *fig.* 51 of the dodecahedron. A solid, bounded by regular figures of two kinds, and which has, at the same time, all the solid angles equal, is called an Archimedean solid. If we limit ourselves to polyhedrons having triangles and squares for faces, such a solid may be contained, 1, by two triangles and three squares (a special case of the three-sided prism); 2, by eight triangles and six squares; 3, by eight triangles and eighteen squares (*pl.* 2, *fig.* 73^b); and, 4, by thirty-two triangles and six squares.

The most important angular solids are the prisms and pyramids. A prism is a solid bounded by two equal and parallel rectilineal figures (forming the bases) and as many parallelograms as each base has sides. It is called three, four, five-sided, as the bases are triangles, quadrilaterals, pentagons, &c. (*pl.* 2, *figs.* 61, 62, 63). The prism is called a right prism if the lateral faces are perpendicular to the bases, otherwise it is oblique. A four-sided prism whose bases are parallelograms, is called a parallelopipedon; when all the faces are squares, it is a cube or hexahedron. If a prism be intersected by a plane parallel to the base, the section formed will be equal

to the base (*pl.* 3, *fig.* 96). The sections of two planes parallel to each other, but not to the base, are equal. *Plate* 2, *fig.* 64, represents a parallelopipedon intersected by a plane, not parallel to the base. Prisms of equivalent bases and equal altitudes are equal to each other (*pl.* 3, *figs.* 97–99). Prisms of equal bases, but of unequal altitudes, are to each other as their altitudes; those of equal altitudes, as their bases; those of unequal bases and altitudes, as the product of the two. A cube whose edge is the unit of length, serves as the unit of measure for determining the volume of a solid; it is called cubic foot, cubic inch, &c., as the edge is a foot, inch, &c. The volume of a cube is obtained by raising the number expressing the length of its edge, to the third power; that of any prism in general by multiplying the area of the base by the altitude, the same unit of measure being used in both.

A pyramid is a solid, bounded by any rectilineal figure as base, and as many triangular planes meeting at the vertex as the base has sides. It is called three, four, or five sided, &c., as the base has three, four, five, or more sides (*pl.* 2, *figs.* 65, 66, 67, 70). If a plane be passed through a pyramid, parallel to the base, the section thus formed will be similar to the base, and will bear to it the same proportion as the square of the perpendicular let fall from the vertex on the section, to the square of the altitude of the pyramid (*pl.* 3, *fig.* 95). A three-sided prism may be divided into three equivalent pyramids, of which two have the same base and altitude as the prism. Hence it follows that every pyramid is $\frac{1}{3}$ the prism of equivalent base and altitude. Consequently, the solid content of a pyramid is obtained by taking $\frac{1}{3}$ of the product of the base by the altitude. If from a pyramid we cut off a smaller pyramid, by a plane parallel to the base, the part that is left is called a truncated pyramid or a frustum. Such a solid is equivalent to three perfect pyramids of the same altitude with it, and having for bases the upper base of the frustum, the lower base, and a mean proportional between the two bases (*fig.* 101). If a three-sided prism be intersected by a plane not parallel to the base, the part remaining is equivalent to the sum of three pyramids of the same base as the prism, but which have for vertices the corners of the triangle in which the prism is intersected by the plane (*pl.* 3, *fig.* 100).

3. OF THE ROUND BODIES.

Among those solids inclosed by both plane and curved surfaces, the cylinder and cone are the best known and most important, as is the sphere among those the whole of whose surfaces are curved; these together are known as the round bodies. The common or typical cylinder is bounded by two equal and parallel circles (forming the bases), and a curved lateral surface uniting their circumferences. The latter is a simple curved surface, and may be generated by the revolution of one straight line around the circumference of a circle, but not in its plane, and constantly parallel to a fixed line which then forms the axis. The cylinder is *right* (*pl.* 2, *fig.*

68), or *oblique* (*fig.* 71), as this axis is perpendicular or oblique to the base. A right cylinder will manifestly be generated by the revolution of a rectangle about one of its sides. On the convex surface of the cylinder, innumerable straight lines may be drawn, parallel to each other and the axis. If a cylinder be intersected by a plane passing through the axis, the section will be a parallelogram (a rectangle in the right cylinder); if the plane be parallel to the base, the section will be a circle equal to the base; if it have any other position, an ellipse will be formed. Every cylinder may be considered as a prism of an infinite number of sides; its volume, as in the prism, will evidently be obtained by multiplying the area of the base by the altitude. The convex surface of the right cylinder is equal to the area of a rectangle whose base is equal to the circumference of the base of the cylinder, and whose altitude is the altitude of the cylinder. The determination of the convex surface of an oblique cylinder is very difficult.

A cone (*fig.* 69) is bounded by a circle as base, and a convex surface running to a point. The latter is a simple curved surface, and is generated by the revolution of a line around the circumference of a circle, and fixed to a point not in the plane. A straight line from the vertex to the middle of the base, is called the axis of the cone, which is termed right or oblique, as this axis is perpendicular or oblique to the base. The ordinary right cone is produced by the revolution of a right angled triangle about one of the short sides. On the convex surface of the cone, from the vertex to the circumference of the base, innumerable straight lines may be drawn, which in the right cone are all equal to each other. Every cone may be considered as a pyramid of an infinite number of sides. Since, then, the pyramid is the third part of a prism of the same base and altitude, the cone will be the third part of a cylinder of the same base and altitude. When a cone is intersected by a plane we obtain, 1, a triangle, when the plane of intersection is parallel to the axis (isosceles, in right cones); 2, a circle, when the plane is parallel to the base; in any other position, one of the three curves, known as the conic sections, which are next in importance to the circle (ellipse, parabola, and hyperbola). When a cone has its upper part or vertex cut off by a plane parallel to the base, it is said to be truncated: this is equivalent to the sum of three cones, whose altitude is that of the truncated cone (or frustum), and which have for bases, the upper base of the frustum, the lower base, and a mean proportional between the two bases. The area of the convex surface of the right cone, is equal to that of a sector of a circle whose radius is the length of the side of the cone, and whose arc is equal to the circumference of the base The area of the convex surface of a truncated cone is equivalent to that of a rectangle whose altitude is the length of the side of the truncated cone, and whose base is equal to half the sum of the circumference of the two bases.

A sphere is inclosed by a single curved surface, all of whose points are equally distant from a point within, called the centre. A straight line drawn from this centre to any point of the surface is called a radius; all radii of a sphere are equal. A diameter is a straight line passing through

the centre, connecting two points of the surface. The section of a sphere by a plane is a circle, which is smaller as the distance of the plane of intersection from the centre is greater (*pl.* 3, *fig.* 103). If the plane pass through the centre, the circle thus formed whose diameter is that of the sphere, is called a great circle. All others are small circles. A line connecting the centre of a sphere with that of a circle of intersection, is perpendicular to the plane of the latter. If two or more circles therefore are parallel to each other, their centres will all be in a diameter of the sphere, perpendicular to their planes; this is called their axis, and its extremities their poles. Every great circle bisects the sphere; two great circles mutually bisect each other, and divide the surface into four parts. If one great circle pass through the poles of another, their planes will be perpendicular. The angle between two great circles is measured by the arc of a circle they intercept, whose plane is perpendicular to that of the two circles (*pl.* 3, *figs.* 103, 110). Two parallel circles include a part of the sphere called a spherical segment, and a part of the surface called a zone. If one of the circles be tangent to the sphere, the zone has only one base. The altitude of a zone or spherical segment is the perpendicular distance between the planes of the bases. The area of a zone is obtained by multiplying its altitude by the circumference of a great circle (*fig.* 102).

The surface of a sphere is equal to the area of four great circles. The solidity of a sphere is obtained by multiplying the third power of the diameter by π (3·1415926) and dividing by 6. If we take a cone, hemisphere, and cylinder, of the same base and altitude (the altitude equal to a radius of the hemisphere), the solidities of these three bodies will be to each other as 1, 2, 3, that is, the cone will be one half the hemisphere, and this, two thirds of the cylinder; a cone, sphere, and cylinder will be in the same proportion, if the first and last have for bases, a great circle of the sphere, and for altitudes, a diameter (*pl.* 3, *fig.* 104).

III. TRIGONOMETRY, OR THE MEASUREMENT OF TRIANGLES.

1. PLANE TRIGONOMETRY.

Plane Trigonometry teaches how to obtain all the parts of a plane triangle, three numerically expressed parts being given, one of which must always be a side. Since every rectilineal figure may be divided into triangles, trigonometry serves for the determination of all rectilineal figures. Geometry gives directly but a single example, viz. the determination of the third side of a right angled triangle, knowing the other two. To obtain this result we square the numbers expressing the lengths of the known sides, add them together, if the hypothenuse is desired, or subtract the less from the greater, for one of the legs. The square root of the result will be the length of the third side.

Instead of the angles, certain quantities are employed whose value depends on that of the angle, and which are called the trigonometrical functions. The most important of these are the sine, cosine, tangent, and cotangent. The explanation of these may be best made in a right angled triangle (*fig.* 105). Here the side opposite an acute angle, as *abc* or *m*, divided by the hypothenuse, as $\frac{ac}{ab}$, is called the sine of that angle, likewise the cosine of the other acute angle, *bac* or *n*; 2, the side opposite an acute angle, *abc*, divided by the other short side, as $\frac{ac}{bc}$, is the tangent of that angle, and likewise the cotangent of the other acute angle, *bac*. Consequently—

$$\text{Sin. } m = \text{cos. } n = \frac{ac}{ab}$$

$$\text{Sin. } n = \text{cos. } m = \frac{bc}{ab}$$

$$\text{Tang. } m = \text{cot. } n = \frac{ac}{ab}$$

$$\text{Tang. } n = \text{cot. } m = \frac{bc}{ac}$$

Consequently, in similar right angled triangles of different size, the sines, cosines, &c., of the homologous or corresponding angles will be equal. If the hypothenuse of the right angled triangle be taken as unity, then the side opposite an acute angle may be taken as the sine of that angle and the cosine of the other. How far the sine, cosine, &c., of an angle varies with its size, may be seen in *fig.* 106. Here *abc* is a quadrant whose radius is taken as unity. Consequently, *de* = sin. *dbc*; *fg* = sin. *fbc*; *be* = cos. *dbc*; *bg* = cos. *fbg*; whence it follows that the sine of an (acute) angle is greater, and the cosine less, as the angle is greater. Consequently, the tangents likewise increase, and the cotangents diminish as the (acute) angle increases. The sines and cosines of (acute) angles are evidently always fractions, while the tangent and cotangent of 45° = 1; tangents of more than 45° are greater than unity, and as the angle approaches 90°, they become very great, tang. 90° = infinity; the same is the case with the cotangents of angles less than 45° and approaching 0.

The sines, cosines, tangents, and cotangents of all acute angles, have been calculated and arranged in tables called trigonometrical tables, which are indispensable in all trigonometrical calculations. The ordinary tables, however, do not contain the sines, cosines, &c., themselves, but their logarithms, as these are more readily employed in calculations.

From the preceding explanations may be readily derived rules for solving all possible cases of right angled triangles. For acute angled triangles, the following two propositions are of the greatest importance:—1, any two sides of a triangle are to each other as the sines of their opposite angles (*pl.* 3, *figs.* 107, 108). In *fig.* 107, the triangle *abc* is divided into two right angled triangles, *abd* and *acd*, by the perpendicular let fall from *a* on *bc*.

From the first we have sin. $m = \frac{ad}{ab}$; from the second, sin. $n = \frac{ad}{ac}$; whence sin. m : sin. n :: $\frac{1}{ab}$: $\frac{1}{ac}$ :: ac : ab. In *fig.* 108, where the triangle abc is obtuse angled, and the perpendicular let fall from c meets only the prolongation of ab, we have sin. $o = \frac{cd}{ac}$, and sin. $n = \frac{cd}{bc}$, whence sin o : sin. n :: bc : ac; so that the preceding proposition holds good also for obtuse angled triangles, if, instead of the sine of the obtuse angle, we take that of the angle which must be added to the obtuse angle, to make two right angles.

2. The sum of two sides of a triangle is to the difference of these sides, as the tangent of half the sum of the angles lying opposite to them, is to the tangent of half their difference. In the triangle abc (*fig.* 109), we accordingly have $ab+ac : ab-ac$ :: tang. $\frac{1}{2}$ $(acb + abc)$: tang. $\frac{1}{2}$ $(acb - abc)$. In the figure, with the lesser of the two sides, ab and ac, namely ac, a semicircle is described cutting ab and its prolongation in d and e, the chords cd and ce drawn, as also df parallel to ce. Then cdf and dce being right angles, we have $be : bd$, that is $ab + ac : ab - ac$ :: $ce : df$. But $ce = cd$ tang. x, and $df = cd$ tang. y; moreover, $x = \frac{1}{2}$ $cae = \frac{1}{2}$ $(acb+abc)$; and $y = x - n = \frac{1}{2}$ $(acb - abc)$, whence the preceding proposition immediately follows.

If we distinguish the angles of a triangle by A, B, C, and the sides opposite to each by a, b, c, we have the following formula for the solution of triangles.

I.—*For right angled triangles, when* A *is the right angle.*

1. Given the hypothenuse a, and a side b; then sin. B $= \frac{b}{a}$; $c = a$. cos. B.
2. Given the hypothenuse a, and an acute angle B; then $b = a$. sin. B; $c = a$. cos. B.
3. Given the two sides b and c; then tang. B $= \frac{b}{c}$; $a = \frac{b}{\text{sin. B}} = \frac{c}{\text{cos. B}}$.
4. Given the side b, and an acute angle B or C; then $a = \frac{b}{\text{sin. B}} = \frac{b}{\text{cos. C}}$; $c = b$, cot. B $= b$, tang. C.

II.—*For acute angled triangles.*

1. Given a side, a, and two angles; then $b = \frac{a \text{ sin. B}}{\text{sin. A}}$; $c = \frac{a \text{ sin. C}}{\text{sin. A}}$.
2. Given two sides, a, b, and an opposite angle, A; then sin. B $= \frac{b \text{ sin. A}}{a}$; $c = \frac{a \text{ sin. C}}{\text{sin. A}} = \frac{b \text{ sin. C}}{\text{sin. B}}$.

Obs. If the side *a*, opposite the given angle, A, be less than the side *b*, there will be two solutions possible, since for B, we may take the acute angle answering to sin. B in the tables, and likewise its obtuse supplemental angle, whence there will also be two values for C and *c*.

3. Given two sides, *a*, *b*, and the included angle C; then tang. $\frac{1}{2}$ A—B $= \frac{(a-b)\,\text{tang.}\,\frac{1}{2}(\text{A}+\text{B})}{a+b}$; A$=\frac{1}{2}$(A + B) + $\frac{1}{2}$(A—B); B$=\frac{1}{2}$(A + B) —$\frac{1}{2}$(A—B); *c* remains as before.

4. Given the three sides, *a*, *b*, *c*. Then indicating by *s*, the half sum of the sides, $\frac{a+b+c}{2} = s$; we have tang. $\frac{1}{2}$A $= \sqrt{\left(\frac{(s-b)\,(s-c)}{(s-a)\,s}\right)}$; tang. $\frac{1}{2}$ B$=\sqrt{\left(\frac{(s-a)(s-c)}{(s-b)\,s}\right)}$; tang. $\frac{1}{2}$ C$=\sqrt{\left(\frac{(s-a)\,(s-b)}{(s-c)\,s}\right)}$.

2. SPHERICAL TRIGONOMETRY.

Spherical Trigonometry teaches the calculation of spherical triangles; that is, of such triangles as are formed on the surface of a sphere, by arcs of great circles. In such a triangle there are also six parts, of which three must be given to determine the rest.

Every spherical triangle answers to a three-sided solid angle, from whose vertex, with any radius, circles are described. Consequently the three sides of the spherical triangle on the surface of the sphere, measure the plane angles at the centre forming the solid angle, and its angles, the inclination of their planes. Hence spherical trigonometry serves for calculating solid angles, and may thus be called solid trigonometry.

On account of what is to follow, some of the most important properties of spherical triangles may here be introduced, although they belong properly to Stereometry. Every two sides of a spherical triangle are together greater than a third (*pl.* 3, *fig.* 111). If through the centre of the sphere, and the sides of the spherical triangle *abc*, we pass three planes, these latter will form a solid angle, whose three plane angles are measured by the arcs, *ab*, *ac*, *bc*. Since any one of these three plane angles is less than the sum of the other two, the same must be true with respect to the three arcs or sides of the spherical triangle.

The sum of the three angles, *aob*, *aoc*, *boc*, is less than four right angles; likewise the sum of the three sides is less than the entire circumference or 360°.

The area of a spherical triangle is proportional to the excess of the sum of its angles over two right angles (called the spherical excess). A spherical triangle, *def*, is called the polar or supplemental triangle of another, *abc* (*pl.* 3, *fig.* 112), where the vertices of the angles of this second triangle are respectively poles of the sides of the first. If *def* be the polar triangle of *abc*, the latter will be, on the other hand, the polar triangle of the former. Every angle of the polar triangle is measured by a semi-circumference minus the side lying opposite to it in the other triangle, whence the name

(supplemental triangle). Hence it follows that the sum of the angles of a spherical triangle must be greater than two right angles, and less than six. A spherical triangle is called right angled, when at least one of its sides is a right angle. If the triangle *abc* (*fig.* 113) be right angled at *c*, and we produce the sides *ab* and *cb* to *d* and *e*, so that $ad = ce = 90°$, and unite *d* and *e* by the arc of a great circle, then *bde* is called the complemental triangle of *abc*, and *de* + the angle $bac = 90°$; as also *bed* + the side $ac = 90°$.

The sines of the sides of a spherical triangle are to each other as the sines of the opposite angles. Let *abc* (*fig.* 114) be a spherical triangle, whose sphere has its centre in *o*, and unity for radius. If now from *c*, on the plane *aob*, we let fall the perpendicular *cd*; from *d* on *ae*, *bo*, the perpendiculars *de*, *df*, and draw *ce*, *cf*; it would be easy to show that the triangles *ceo*, *cfo* are right angles, and consequently that *ce* = sin. *cod*, = sin. arc *ca*, *cf* = sin. *cob* = sin. arc *cb*.

One of the most important formulæ in spherical trigonometry is that which expresses the cosine of an angle of a triangle, in terms of the three sides. To obtain this formula we may employ *fig.* 115, where *abc* is a spherical triangle, *o* the centre of the sphere, *cd* and *ce* tangents to the sides *ca* and *cb*, meeting the radii *oa* and *ob* in *d* and *e*. Drawing *de*, then according to a proposition of plane trigonometry, $\overline{de}^2 = \overline{cd}^2 + \overline{ce}^2 - 2cd.\ ce.$ cos. *dce*; and also $= \overline{od}^2 + \overline{oe}^2 - 2od.\ oe.$ cos. *doe*. But (indicating the radius by *r*) $cd = r.$ tang. *ac*; $ce = r,$ tang. *bc*; angle *dce* = angle $acb = c$; $od = \frac{r}{\text{cos. } ac}$; $oe = \frac{r}{\text{cos. } bc}$; $doe = ab$. Substituting these values, we have cos. $acb = \frac{\text{cos. } ab - \text{cos. } ac.\ \text{cos. } bc}{\text{sin. } ac.\ \text{sin. } bc}$. If we indicate, as is customary, the angles by the capital letters A, B, C, and the sides corresponding to these letters by *a*, *b*, *c*, respectively, the preceding formula becomes cos. $C = \frac{\text{cos. } c - \text{cos. } a,\ \text{cos. } b}{\text{sin. } a - \text{sin. } b}$. If, however, we indicate the sides and angles by small letters, so that the side a' answers to the angle *a*, &c., then cos. $c = \frac{\text{cos. } c' - \text{cos. } a',\ \text{cos. } b'}{\text{sin. } a'\ \text{sin. } b'}$. These formulæ are not suited to calculations of angles by means of logarithms.

Two simple rules may be adduced, of universal application in calculating right angled spherical triangles. If, for instance, we write down the sides and angles of one of these in their natural order of sequence, omitting the right angle altogether, and taking for each side about the right angle, 90— that side, we shall have, 1, the cosine of any part = the product of the cotangents of the including parts, and 2, the cosine of any part = the product of the sines of the second and third parts following. Thus, if *c* be the right angle, and we take b' for $90 - b$, and a' for $90 - a$, we shall have as the order of succession, a', B, *c*, A, b', a', B, *c*; then, for example, cos. a' = cot. B, cot. b'; and cos. A = sin. B, sin. a', &c. The solutions thus obtained may be ambiguous when a part is given by its sine, since any

two angles or arcs, which, when added together, make 180°, have equal sines. Thus, if in the triangle ABC, A and a are given, we have sin. $B = \frac{\text{cos. } A}{\text{sin. } a'}$ whence there may be two values for B—one above, the other under, 90°. In fact, *pl.* 3, *fig.* 116, shows that the two triangles, *bac* and *ba''c*, have a side, *bc*, common, and the angles opposite to A equal (since the angles *bac* and *ba''c* are equal), while all the remaining parts of the one triangle are supplements (180 — the part) of the corresponding parts in the other.

In the solution of acute angled spherical triangles, two cases occur in which the results of trigonometrical calculations are ambiguous: 1, when two sides and the angle opposite the smaller of these are given; 2, when two angles and the side opposite the smaller one are given. *Fig.* 117 illustrates the latter case. If, in the triangle *abc*, we have given the angles *abc* and *acb*, and the side, *ac*, opposite the smaller angle, then a second and entirely different triangle, *acb''*, may be constructed, of very different parts, provided that *ab'* is so taken that its prolongation $ad = ab$, and consequently $abc = adc = ab''c$.

In astronomy, it is frequently desirable to ascertain what effect a very slight alteration of one part (a side or angle) of a triangle produces on another part, all the rest remaining unchanged. These effects may be often determined by geometrical considerations, as, for instance, when the change sought is that which alteration of an angle of a spherical triangle produces on the opposite side. In *fig.* 118, convert the triangle *acb* into *acb''* by a slight alteration of the angle *acb*, and indicate the change of the angle *c* by δc; that of the opposite side, c' by $\delta c'$. If we let fall from *b* on *ab''*, the perpendicular, *bx*, we may take $ax = ab$, and $b''x = \delta c'$, and we will have $\delta c' =$ sin. *abc*, sin. a', δc.

The application of trigonometry, both plane and spherical, to geodesy, is of great importance. The piece of land to be surveyed is divided into triangles whose corners are indicated by signals; of the sides of these triangles only one need be measured, as a basis from which, with the help of the observed angles, to calculate the remaining sides. In this respect, some special formulæ are still necessary, of which we here give but one example: —given the angular interval of two signals of moderate height above the horizon, to deduce the horizontal angle of the two points of the horizontal plane on which the signals are erected. In *fig.* 119, let *a*, *b*, be the signals observed from *o*; and let the angle *aob* be measured. If we suppose a sphere constructed with *o* as the centre, and from *z*, the vertical point or zenith of *o*, the great circles *zac*, *zbd*, described, *cod* being the horizontal plane, *cod* or *czd* will be the horizontal angle sought. If we make the angle $aob = m$, *cod* or $czd = m + x$; $ac = h$, $bd = h'$, then the correction of the measured angle m is $x = \frac{1}{4}\,([h + h']^2 \text{ tang. } \frac{1}{2}\,m - [h - h']^2 \text{ cot. } \frac{1}{2}\,m)$.

For the solution of triangles which, supposing the earth to be a perfect sphere, may be taken for spherical, three methods are principally used: they may be either considered as spherical triangles, in which case the central angle corresponding to each side is deduced from the known radius of the earth; or from the angles of the spherical triangle, the angles of their

chords are obtained, and the triangle of these solved as a plane triangle; or finally, the spherical triangle is treated as plane, in which case a correction is applied to the angles, each one being diminished by about the third part of the spherical excess. This latter rarely reaches five seconds.

Knowing the angles and sides of the triangle, as also the relative positions of the signals, we have still to determine the angle which one of the lines makes with the meridian. To this *fig.* 120, *pl.* 3, has reference, where *z* is the zenith, *p* the pole, *s* the pole star, *zs* a great circle. Hence the following problem is to be solved by means of the formulæ of spherical trigonometry: From the sides *ap*, *ab* (*fig.* 121), and the angle *pab* of a spherical triangle *abp*, to determine the side *pb*, and the angles *p* and *b*, where *pa* and *pb* are the complements of the breadths of the positions A and B, and the angle *p*, the difference of their lengths.

IV. HIGHER GEOMETRY, OR GEOMETRY OF CURVES.

The higher Geometry treats, as above mentioned, of curved lines, curved surfaces, and the solids bounded by these. In applying Algebra and Analysis to Geometry, and establishing its principles by calculation, a marked difference is observed between it and the lower Geometry. This application of Analysis to Geometry is known as Analytical Geometry, which is by no means limited to the cases of the higher Geometry, since straight lines, the circle, and planes may be treated of analytically. The position of a point in a plane is indicated in Analytical Geometry by its co-ordinates (so called). By this is generally understood the distance of a point from two straight lines whose position is known, generally at right angles to each other, and called the axes (of ordinates and abscissas). The distances are parallel to the axes, and are known as the abscissa or ordinate of the point, accordingly as they are parallel to the axes of abscissas or of ordinates. The two together are called co-ordinates. The point of intersection of the two axes is called the origin of co-ordinates; since the two co-ordinates of a point form a parallelogram with the portions of the axes cut off by them, these latter may also be considered as co-ordinates; hence the ordinate only is generally drawn parallel to the corresponding axis, and the portion of the axis of abscissas cut off by it, called the abscissa. Thus if in *pl.* 3, *fig.* 106, *bc* represent the axis of abscissas, and *b* the origin of co-ordinates, supposed to be rectangular; then the perpendicular *fg* let fall from *f* on *bc*, will be the ordinate, and *bg* the abscissa of the point *f*.

Polar co-ordinates are different from the co-ordinates first explained. Here we assume only one fixed straight line, and a point in it (called the pole) as known, and determine the position of every other point by its distance from the pole, or the length of the connecting line (Radius vector) between point and pole, and the angle inclosed between it and the fixed straight line; a point in space is known by its distance from these known planes, cutting each other in the origin of co-ordinates, and generally

perpendicular to each other. If, however, a point in space is to be determined by its polar co-ordinates, a line and two angles are required.

Every line, straight or curved, is in analytical geometry expressed by an equation from which all the peculiarities of the line may be derived by calculation. If we suppose all co-ordinates to be expressed in numbers, and indicate the abscissa by x, and the ordinate by y, then for every line the dependence between abscissa and ordinate of one and the same point of the line may be expressed by an equation, which holds good for every point of one and the same line. Thus for the equation of the straight line we have $y = ax + b$, or $ax + by + c = o$.

Curved lines, or curves, are divided into curved lines of simple curvature which lie in one and the same plane, and into curved lines of double curvature which lie in different planes. The former, to which we here limit ourselves, are again subdivided into algebraic, which may be expressed by an algebraic equality; and transcendental, whose equations are transcendental, that is, consist of an infinitely great number of terms.

Algebraic curves are divided according to the degree of their equations, into lines of the first, second, third, &c., order. Since, however, the straight line alone is expressed by an equation of the first degree, and is consequently the only line of the first order, we term lines of the second order, also, curves or curved lines of the first class; lines of the third order, curves of the second class, &c.

Every curved line may have a touching line or tangent, as well as the circle. By this is understood a straight line which has one point in common with the curve, and indicates the position of the curve with respect to that point. Thus in *pl.* 3, *fig.* 134, a tangent is drawn through the point *m*. The part of the axis of abscissas between the ordinate and the tangent of a point, is called the sub-tangent. If we erect a perpendicular to a tangent at the point of tangency, and prolong it to the axis of abscissas, the part of the perpendicular (*mn* in the figure) contained between the latter and the point of tangency, is called the *normal;* that part of the axis of abscissas (*np* in the figure) between normal and ordinate, the *sub-normal.*

The most important curves, as well as those of most frequent occurrence, belong to the first class. These are the ellipse, parabola, and hyperbola. They are also called the conic sections, because they are produced by intersecting a cone by a plane in various directions. If the plane of intersection be parallel neither to the axis nor side of the cone, the outline of intersection is called an ellipse (*pl.* 1, *fig.* 55). This is a closed curve line, having the peculiarity that in one of its axes there are two points. termed the foci, so situated that the sum of the distances of any point of the curve from the foci, will be the same. The more the direction of the generating plane approaches a perpendicular to the axis of the cone, the more do the foci approach each other; and when the perpendicular is attained, the foci meet in the centre, and the ellipse becomes a circle. Every line passing through the centre of an ellipse, is called a diameter; the longest diameter (called *major axis*) is that which passes through the

foci; the shortest (called *minor axis*) is perpendicular to the former and bisects it.

The distance from a focus to the centre is called the eccentricity (in the circle = 0); the equation of the ellipse is $y^2 = \frac{b^2}{a^2}(a^2 - x^2)$, where a and b are the semi-major and minor axes. In the circle $a = b$, therefore, $y^2 = a^2 - x^2$ is the equation of the circle of radius, a.

A hyperbola is produced when the intersecting plane is parallel to the axis of the cone. As this intersection always meets the base of the cone, the hyperbola is an open curve. It also has two foci, the difference of whose distance to any point in the circumference will always be the same. It is composed of two equal parts, each of two branches, which, stretching into infinity, approach continually without ever meeting two straight lines (the asymptotes) which intersect each other in the centre of the major axis. The equation of the hyperbola is $y^2 = \frac{b^2}{a^2}(x^2 - a^2)$. When $a = b$, it becomes $y^2 = x^2 - a^2$; such a hyperbola is called equivalent. The asymptotes of this form a right angle with each other.

The parabola is produced when the plane of intersection is parallel to the side of the cone; it also is an open curved line, but has only one focus. Every point of the curve is equally distant from the focus and a fixed straight line called the *directrix*. It also consists of two symmetrical, infinitely extending branches, which unite in a point half way between the focus and directrix, called the vertex. A straight line drawn through the vertex and the focus is called the axis. The equation of the parabola is $y^2 = px$.

The following algebraic curves may be mentioned in addition:

1. *Parabolas* of higher orders. These are curves in which a power of the ordinate is proportional to some other power of the abscissa: their general equation is $y^m = ax^n$. If $n = 1$ and $m = 2$, the equation becomes a quadratic (thus, $y^2 = ax$ is the same with the common or Apollonian parabola); a cubic when $m = 3$, &c. The parabola of Neil (*pl.* 3, *fig.* 124), whose equation is $y^3 = ax^2$, is particularly remarkable. It is that curve in which a heavy moving body falls equally in equal time.

2. The *cissoid* (*fig.* 122), a curve of the second class, discovered by the Greek geometrician, Diocles. It consists of two infinite branches, uniting in a point, a, and continually approaching a tangent of the circle (the asymptote) without ever meeting it. Its equation is $x^3 = (a - x)\, y^2$.

3. The *conchoid* (*pl.* 3, *fig.* 123), a curve of the third class, discovered by Nicomedes, whose equation is $\frac{x^2y^2}{(b+y)^2} + y^2 = a^2$. Its construction is very simple: draw a straight line, and out of this line take any point, a; from this point draw a straight line cutting the firstin q; from q take off $qm = qn$ in this second line equal to a given or fixed length: m and n will be points of the two infinite branches of the conchoid, which also has qq for its

asymptote. Müller of Gröningen has proposed to apply the conchoid to the measurement of barrels.

4. The *cardioid* (*fig.* 125), a curve of the third class, properly an epicycloid of two equal generating circles. Its equation is $y^4 - (a^2 + 2ax - 2x^2)\, y^2 - 2ax^3 + x^4 = 0$.

5. The *lemniscata* (*fig.* 130), a curve of the third class, discovered by Jacob Bernouilli, and investigated by Euler and Fagnano, whose equation is $(x^2 + y^2)^2 = 2\, a^2\, (x^2 - y^2)$.

6. The *ophiuride*, discovered by Uhlhorn, for the trisection of angles, constructed as follows (*fig.* 131): Construct a right angle, *abc*, with determined sides, *ab*, *bc*; draw from *c* to any point in the line *ab*, or its prolongation, a straight line, *cd*; erect at *d* a perpendicular, *dn*, to *cd*, and upon this, from the end of the other side of the angle, let fall a second perpendicular, *am*, then *m* will be a point of the curve. Taking $ab = a$, $bc = b$, the equation of the ophiuride will be $x^3 + (y^2 - ay)\, x - by^2 = 0$.

7. The *scyphoid*, according to Uhlhorn, is formed in the following manner (*fig.* 132): If, from any point, *o*, out of an unlimited straight line, *yy'*, a perpendicular, *ob*, and any oblique line, *oc*, be drawn to the line, and through *c* a line, *nz*, perpendicular to *oc*, and on *nz* the distances $cm = cm' = bc$, then will *m* and *m'* be points of the scyphoid. Taking $ob = a$, then, with *o* as origin of co-ordinates, *ob* as axis of abscissas, and *yy'* as ordinates, the equation of the scyphoid will be $y^4 - 4a\, (a - x)\, y^2 - (a - x)^4 = 0$.

Examples of curves whose equations are most readily expressed by polar co-ordinates, are afforded by the spiral lines (*pl.* 1, *fig.* 51), which wind continually around a fixed point, either continually approaching to, or receding from it, according to a given law. The simplest of these is the Archimedian or equable spiral (*pl.* 3, *fig.* 133), which is generated when a point moves uniformly along the radius of a circle, this radius describing an uniform rotation around its extremity, so that the distance of the moving point from the centre is always proportional to the angles described by the radius. It is generally provided, in addition, that the moving point shall meet the circumference of the circle by the time that the radius has described its first entire revolution.

Spirals may also be described on the surface of a cylinder, a sphere, or a cone: the well known screw line (*pl.* 1, *fig.* 52) belongs to the cylindrical spirals.

The cycloid or trochoid belongs to the transcendental curves. This is described by a point in the circumference of a circle which rolls along a straight line until it has completed a revolution; the circle, curve, and line, being supposed to continue in the same plane (*pl.* 3, *fig.* 135). If the revolution be started when the point lies in the straight line (at *a*), and is consequently the point of tangency between the circle and line, and continues until it again meets the straight line (at A), then the line A*a*, called the base of the cycloid, will be equal to the circumference of the generating circle. The cycloid cuts the base at A and *a'*, therefore the

point i', lying half way between the two, called the vertex, is the furthest distance from the base, this distance being equal to a diameter of the generating circle. When the generating point lies without the circle, the cycloid produced is called the *curtate* or *contracted* cycloid (*fig.* 136). If it be within, it becomes *prolate*, or *elongated* (*fig.* 135[a]).

If the circle with its generating point revolve, not on a straight line, but upon the circumference of another circle, fixed, and in the same plane, then the curve produced will be an *epicycloid*, if the revolution be on the outer side of the fixed circle, and a *hypocycloid* when on the inner. We have here, as in the cycloid, the same distinctions into *ordinary* or *common* epicycloid (*figs.* 137, 140); *prolate* or *elongated* (*figs.* 138, 141); and *curtate* or *contracted* (*figs.* 139, 142).

Another transcendental curve, or rather genus of curves, is the *quadratrix*, a curve line, described on a common axis with any other given curve, and indicating by its ordinates the area of the latter curve, since their ordinates are as the areas answering to the corresponding abscissas, with the given line as axis of ordinates. The oldest quadratrix is that of Dinostratus (*fig.* 126): let *ab* be a diameter of a circle, and the triangle *acb* so constructed that *the height cn* : *the base ab* : : *angle cab* : *a right angle*, then *c* will be a point of the quadratrix, whose equation is $x\ g\ \frac{\pi(a-x)}{2a} - y^0$.

Another construction of the quadratrix is given by Tschirnhausen (*fig.* 127). Let *adb* be a semicircle, *o* the centre, and *m* a point in the circumference, furthermore *n*, a point of the diameter which lies in such a manner that *quadrant ad* : *arc am* : : *ao* : *an*, and draw through *m* and *n* to *ao* and *do* parallels meeting in *p*, then *p* will be a point of this quadratrix whose equation is $y = \sin.\ a\ \frac{\pi x}{2a}$.

We have still to explain the meaning of the terms *evolutes* and *involutes*. Suppose that on the elevated side of a curved line, a perfectly flexible thread be laid. If, now, this thread be kept continually stretched, and unlapped by degrees from the curved line, its end will describe a new curve, which is called the *involute* of the old curve, this latter being the *evolute* of the former. Thus the parabola of Neil is the evolute of the common parabola. In *pl.* 3 (*fig.* 128), the involute of the circle is represented, which is constructed as follows: Through any points, *b*, *c*, *d*, of a circle, tangents are drawn, and on these the points, b', c', d', so taken that the tangents, bb', cc', dd', shall equal the length of arcs of circles contained between the points of tangency and a fixed point, *a*. The points b', c', d', will then be points of the involute of the circle, which is a transcendental curve.

Among the solids produced by the higher curves, the spheroid is the most important, resembling the sphere, and like it having a centre in which every diameter is bisected, but differing in these diameters being of unequal length (*pl.* 2, *fig.* 73). Among all the diameters of a spheroid, three, perpendicular to each other, called its axes, are best worthy of mention.

A plane passed through one of the three axes forms an ellipse by its intersection with the surface. When two axes are equal, the spheroid becomes *elliptical*, being generated by the revolution of an ellipse around one of its two axes (forming an ellipsoid). A paraboloid is generated by the revolution of a parabola about its axis, and a hyperboloid by that of a hyperbola.

V. APPLIED GEOMETRY.

1. GEODESY, OR SURVEYING.

Practical geometry, which is itself only a part of applied mathematics, embraces, in a restricted sense, 1, the greater and lesser arts of surveying, or geodesy; 2, descriptive geometry, or theory of proportion. In a restricted sense, we understand by practical geometry only the first of these divisions, which proposes to itself the problem, accurately to determine the size, shape, and position of a larger or smaller part of the earth's surface, and to represent it pictorially on a reduced scale.

We distinguish, as above mentioned, a lower geodesy or field surveying, which has to deal only with small parts of the earth's surface, as a field, or estate, and a higher geodesy, having reference to whole countries.

Under geodesy are also reckoned, generally, *levelling* and *surveying* of mines.

The first problem in field surveying is to mark off a straight line. This is done by means of straight cylindrical staves of wood, from 6 to 8 feet high, and 1 to $1\frac{1}{2}$ inches thick, with iron points at the lower end for more convenient insertion into the ground; together with a number of stakes, called also arrows, pickets, &c. Of these staves, A and B are placed perpendicularly in the ground about 100 feet apart, and a third, C, still further forward in the same straight line. In order to place these staves in the same straight line, we may have them so adjusted, that, standing behind A, the others, B and C, shall both be covered by it; or A and B may be covered by C in the line of sight. This latter method is, perhaps, preferable. We must proceed in the same way to extend the line of these staves.

The second problem is to measure a line which has already been staked off. This is done either by means of the measuring chain, which is most generally employed, or by measuring tapes or threads, which are commendable for their cheapness and convenience, but do not afford accurate results; or, finally, by measuring staves, which give by far the most correct measurements.

With stakes and a chain, or some other means of measuring a given line, quite a number of the more difficult problems may be solved, without any other apparatus. We can, in the first place, survey any irregularly curved line on the surface of the ground, as, for instance, the outline of a field or plain (*pl.* 4, *fig.* 1). To this end, a straight line, AB, is staked off, and on this as many successive distances, A*a*, *ab*, *bc*, &c., as possible, measured.

The distances, *aa'*, *bb'*, *cc'*, &c., from *a*, *b*, *c*, &c., are next to be measured at right angles to the base (which may be done by the eye, or more accurately with a string divided as the numbers 3, 4, 5, of a right angle). The measured distances of both kinds, the abscissas, A*a*, A*b*, A*c*, &c., as also the ordinates, *aa'*, *bb'*, &c., are traced on paper on a reduced scale, and the points, *a*, *b*, *c*, &c., united. The accuracy of the outline will be evidently in proportion to the number of abscissas and ordinates measured. The outline may sometimes be such as to render it advisable to stake off two lines, as in *fig.* 1, whose relation to each other must be known.

In the second place, the distance between two points may often be determined even when no direct measurement is possible. Three principal cases are here to be distinguished: 1. When the distance between two points cannot be measured directly, but only that from a third point to each of these two (*fig.* 2). In this case, we measure the distances, CA, CB; continue the prolongations of these lines beyond C, towards D and E; take CE = CA, and CD = CB, or the reverse; the measured distance from D to E will be the same as that from A to B. It is much more convenient, when the prolongations of the lines, AC and BC, cannot be made equal to them, to take a certain part of the distance, as one fourth $Cd = \frac{1}{4}Cb$, $Ce = \frac{1}{4}Ca$; then *de* will be the same fraction of AB, or $de = \frac{1}{4}AB$, or $AB = 4de$. 2. When we can reach only one of the two points whose distance from each other is desired, as in *pl.* 4, *fig.* 3. Here we assume any point, C, at pleasure, from which B may be reached in a straight line, measure CB, and continue the prolongation of this line to D, so that CD = CB, and then in the direction DE, making the angle CDE = CBA. (To effect this take on BA and BC, any portions, B*a*, B*b*—five feet, for instance—measure the distance *ab*, make D*d* = B*b*, and with a beam compass, from *d* as centre, with *ab* as radius, describe an arc, intersecting another arc from D as centre, with *a*B as radius. Stake off the line DE through *e*, and we shall then have the direction of the required angle.) We then continue in the direction DE or D*e* until we reach a point, E, which lies in the same straight line with C and A, as ascertained by two staves. The distance DE will then equal AB. *Fig.* 4 represents another method of attaining the same result: Take on AB any point, C, between A and B, and then a point, D, whose distance from B and C may be directly measured; continue the lines CD and BD beyond D, making DF = CD, DE = DB. Finally, draw EF, and continue it to a point, G, in the same straight line with D and A; EG will be the distance required. We may here also, instead of the whole line, BD, CD, take a fractional part of these prolongations; thus, if we make $De = \frac{1}{4}DB$, and $Df = \frac{1}{4}CD$, then, if *g* lie in a straight line with AD, as well as with *ef*, *eg* will $= \frac{1}{4}AB$. 3. When we can reach neither of the points, A, B (*fig.* 5). In this case, many methods may be employed; the one represented is perhaps the simplest: lay off the line CD approximately parallel to AB, and on it take *c*D equal to an aliquot part, as $\frac{1}{4}$ of CD; make D*ca* = DCA, and D*cb* = DCB, taking the distance *ca* so that *a* may be in the line AD, and D*b* so that *b* may be in the line BD, then *ab* will, in our figure, be $\frac{1}{4}$ of AB (the line *cb* is not represented).

To determine with staves alone, the height of an object whose foot cannot be reached, we employ two of unequal lengths, DE and FG (*fig.* 8). Erect the two staves so that the eye, placed at the ground at J, shall see their summits, E and F, in the same line with that of the object, B. The staves being of known height, measure the distances, JD and DG (together equal to JC) : with the same staves repeat the operation at another point of the line, JA, as at C′ and D′, obtaining the values J′D′ and D′C′ (together = J′C′). As the triangles JDE, JGF, and JAB, are similar, and also J′D′E′, J′C′F′, and J′AB, as well as GF = C′F′ and ED = E′D′, we will have

$$\begin{array}{l} JD : DE :: JG : GF \\ JD : DG :: JA : AB \\ \hline JG : GF :: JA : AB :: JG : JA :: GF : AB. \end{array}$$

$$\begin{array}{l} J'D' : DE :: J'C' : GF \\ J'D' : DE :: J'A : AB \\ \hline J'C' : J'A :: GF : AB. \quad \text{But} \\ JG : JA :: GF : AB \\ \hline JG - J'C' : JA - J'A :: GF : AB. \end{array}$$

JG and J′C′ are, however, known; JA — J′A = JJ′ is also known, consequently $AB = \frac{GF \times JJ'}{JG - JC'}$.

The shadow of an object when the sun shines may be used for measuring its height, although this method has no claim to great accuracy. Erect a perpendicular post or staff, of known length, and measure as nearly as possible at the same time, the length of its shadow and that of the object; then the length of the staff will be to that of the object as the lengths of their shadows. If in the line of the shadow we erect a post so that the end of its shadow coincides with that of the object's shadow, then the same proportions will hold good, and the method is at the same time more convenient (*pl.* 4, *fig.* 6).

If the foot of the object to be measured cannot be reached, we may apply the preceding method on two different days, when the sun has a decidedly different height, best of all at the time of true noon, when the shadow falls exactly in the true meridian. If we indicate the length of the object's shadow at the two different times, by C and C′, those of the post's shadow by *c*, *c*′, and the length of the post by *a*, then the height of the object will be $\frac{a(C - C')}{c - c'}$.

Instead of the shadow we may use a horizontal reflecting surface (of oil or mercury). Erect at any point, D (*fig.* 7), a staff, DE, of known length, not to exceed a few feet; find a place, C, between the staff and the object, where the mirror shall reflect the top of the object to the eye placed at E. In this case, the triangles, CDE, ABC, are similar, and if AC can be mea-

sured, the height desired will $= \frac{AC.DE}{CD}$, or (substituting c for AC, a for DE, and d for CD) $= \frac{ca}{d}$. If the foot of the object cannot be reached, the same process may be repeated with the same staff, at another place, D′, and the height will $= \frac{c'a}{d'}$, if C′D′$= d'$, AC′$= c'$. If now, CC′$= b$, and consequently, $c = c' + b$, then $\frac{c'a}{d'} = \frac{(c'+b)\,a}{d}$, whence $c' = \frac{bd'}{d-d'}$, and the height required $= \frac{ab}{d-d'}$.

The describing of a part of the earth's surface, *i. e.* making a perfect representation of it on a reduced scale, is to be considered as one of the principal problems in surveying. Three methods may be employed when only a small part, easily overlooked, is in question: in these the plane table is the most convenient instrument to be employed. 1. By *sighting forwards and measuring*. Sight from a given station A (*pl.* 4, *fig.* 9), situated in the inside or in the circumference of the figure, towards all its corners, which are to be indicated by signals or other marks; measure also the distance of this point from all the corners, determine the sight lines on the plane table by means of a diopter ruler, and mark off, according to a scale, the proportional lengths of the distances above mentioned. By connecting the extremities of the lines thus obtained, we shall have a figure similar to that of the field. 2. By *going round the figure*, or *sighting backwards*. All the sides of the figure (except two) must be measured, and sights taken from one corner to the others. This is also called surveying the figure from the circumference. The method is inconvenient, but oftentimes the only one practicable (*fig.* 11). 3. *Surveying from two stations.* Measure a base line, AB (*fig.* 9), and sight from its ends to all the corners of the figure; transfer this base, reduced, to the paper, and draw from its extremities the lines of sight: the intersections of these two sets of lines will determine the corners of the figure. This method, when it can be employed, is always preferable to the other two. It is more fully illustrated in *pl.* 5 (*fig.* 57). Here *ab* is the base, which may be 100 or 1000 feet long. After it has been measured, the plane table is set up at A, and from *a*, sights taken to the other extremity of the line, as also to all the principal points visible from A, as C, D, E, F, &c. The corresponding sight lines are then to be drawn on the table by means of the sight or diopter ruler. The length of the base line is then to be marked off on the sight line running towards *b*, on a reduced scale, as $\frac{1}{1000}$ or $\frac{1}{5000}$; and the table removed to B. It is here to be set up in such a manner that the point *b* lies directly over that part of the base answering to *b*. It is furthermore erected so that the sight line to *a* corresponds with the line *ab* drawn on the table. The points C, D, E, F, &c., already sighted from A, are to be sighted from B, and the corresponding sight lines drawn upon the plane table. Their intersec-

tions with those drawn from the other extremity of the line, determine the position of these points on the reduced plane of the table.

If a great surface is to be measured—an entire country, for instance—a trigonometrical net-work must be constructed, as already mentioned under the head of Trigonometry. This consists in dividing the part of the earth's surface in question, into a great number of connected triangles, whose corners form stations visible one from the other. In these triangles, only one side, rarely over $1\frac{1}{2}$ mile long, needs to be measured; in addition to which, the angles must be measured with a theodolite. Care must be taken that the angles of these triangles be neither too acute nor too obtuse; those most nearly equilateral are most convenient. The net must be so arranged that each sheet of the plane table contains at least two of the corners of the trigonometrical net. In *pl.* 4, *fig.* 10, AB represents the base; from this the points D and C are determined, by measuring the angles BAC, DAB, and ABC, DBA, and two triangles thus obtained, whose sides, AC, BC, AD, BD, may be calculated trigonometrically. AD may now be taken as base, and the point E determined; as also K, from the base DE, &c. In this manner the network, ABCDEKH, is produced. It will add greatly to the accuracy of the work to determine each point from several stations if possible. This serves to control the various measurements. Suppose the point K to be determined from DH, and likewise from DE, if it should fall towards L, some error must have occurred, which must be detected either by repeated measurements or by special calculations to which we have not time here to refer.

A very important problem, and one of frequent occurrence, is to determine the point on the plane table corresponding to the one where it was originally set up; this, knowing the positions, α, β, γ, of the three points of the field, A, B, C (*fig.* 64–68). If the triangles, α, β, γ, can be brought into a position perfectly parallel to the field triangle ABC, then the point required will be determined by applying the sight ruler at α, β, γ, and sighting towards A, B, C; the intersections of these three lines will determine the point. It is very difficult, however, to attain this parallel position. If the two triangles are not parallel, the three sight lines will form a triangle, by means of which the desired point may be attained. We cannot here go into the minute details of the operation.

To determine the area of a rectilineal figure, all that is necessary is to divide it by diagonals into triangles, whose individual areas are to be computed from their ascertained bases and altitudes, and added together. The figure may also be divided into trapezia and triangles, which method is sometimes preferable. When the figure to be calculated is curvilineal, the latter method may sometimes be employed (as in *fig.* 13), if the parallel lines are drawn so closely to each other that the included parts of the circumference may, without material error, be considered as rectilineal. In the case represented in *fig.* 12, the two triangles, ABC, BCD, are first calculated, then the mixed lined parts by which the triangles exceed the curvilineal figure. This latter is effected by dividing them into trapezia and triangles, by perpendiculars erected, and subtracting their sum from that of the

triangles. In *fig.* 14, the computations are to be made in the same way, and the sum of the mixed lined portions added to that of the triangles. In *fig.* 15, the parts BCL, DEK, &c., may be determined in the same manner.

Levelling forms a particularly important branch of Geodesy. This consists in ascertaining the difference in height of two points of the earth's surface, by direct measurement, and not by projection or calculation. The object of levelling may be thus expressed generally: to ascertain how much further one point of the earth's surface lies from its centre, than another point. As a general rule, it is not great elevations that are here in question, but simply the gradual rise and fall of the ground. The instruments necessary for this purpose will be described hereafter; the operation itself is explained by *pl.* 4, *figs.* 16–19. In general, two methods for determining the difference of height of two points, may be distinguished—either to set up at one of the two points (*fig.* 16), or between the two (*fig.* 17): the latter is, perhaps, preferable. The distance between the two points whose difference in height is to be ascertained, must not be very great (from 1—2000 feet). At a greater distance, intermediate stations must be assumed, which the nature of the surface sometimes renders necessary for slight distances. Thus, in *fig.* 18, the difference of elevation between A and J is to be ascertained by means of the intermediate stations, C, E, G, assumed in the lines A, J; four levellings are here required. In *fig.* 19, this difference between A and D is determined by means of the two intermediate stations, B and C.

It will be necessary to add, in conclusion, a few words with respect to *topographical drawing*. This consists in representing portions of the earth upon paper, in their natural appearance. A topographical drawing differs from a chart in its much larger scale, which admits of the insertion of more details. While, for ordinary maps or charts, the scale rarely exceeds $\frac{1}{20000}$ of the natural size, in special plans for economical or military purposes, it may amount to $\frac{1}{2500}$, so that one line, or $\frac{1}{100}$ of a foot in the drawing, would represent 25 feet of ground.

A topographical drawing represents not only streams, roads, houses, forests, &c., but also mountains and valleys; and this in such a manner that from the drawing the steepness of the declivities may be ascertained. This is done, according to the almost universally adopted method of the engineer Lehman, by means of rectangular pen strokes, made side by side, in such a manner that the amount of black is to the amount of white, as the given angle of inclination to 45° minus the same angle; consequently, a horizontal surface appears entirely white; that inclined at an angle of 45°, entirely black; at 5, 10, 15, 20° of slope, the breadth of each black space is respectively $\frac{1}{8}$, $\frac{2}{7}$, $\frac{1}{2}$, $\frac{4}{5}$, of the white interval succeeding; while at 40, 35, 30, 25 degrees in succession, the reverse order takes place. This method is not calculated for slopes of from 45° to 90°, for the simple reason that they seldom occur, are always much broken in their declivities, and are entirely impracticable for military purposes, which the inventor had chiefly in view. *Figs.* 58–60, on *pl.* 5, are intended to elucidate the preceding remarks.

Fig. 60 represents the environs of the town of Greitz, and *fig.* 59, the plan and profile of a mountain top, drawn according to the declivities of the surface.

2. DESCRIPTIVE GEOMETRY.

A. Projection.

a. Projection in vertical and horizontal planes.

By the theory of projection is understood in general, a combination of all those propositions by whose application we are enabled to represent an object as it appears to us in a certain direction, and from a certain distance. If we suppose lines to be drawn from our eyes to all points of the object, representing lines of sight, a pyramid of rays will be formed, whose base is the surface of the object, whose sides are the rays of sight, whose apex is the eye, and whose altitude is the perpendicular distance of the object from the eye. If we suppose a plane to be passed through this pyramid, parallel to its base, according to the principles of similar figures and the laws of Stereometry, we will have an image in the plane of intersection which is similar to the body in question, and which is smaller as the distance of the plane from the eye is less. If we suppose the object to be at an infinite distance, the pyramid produced will be of great altitude, and the angle made by the sight rays with the base of the pyramid will be obtuse; if the section be made tolerably near the base, we may assume the portions of the sight rays thus cut off as parallel to each other, and perpendicular to the base of the pyramid. The intersecting plane is called the plane of projection, and upon it the image of the object is supposed to be represented.

According to the preceding principles we can find the projection of a point, by drawing a perpendicular from it to the plane of projection; the intersection of the line with the plane will be the projection of the point. Nevertheless, as the distance from the plane at which the point is situated is not determined, we cannot ascertain its actual position from this projection. This will be possible, however, if we employ a second plane, upon which we may suppose the distance of the projection from the point itself to be described. The first plane is called the *plane of elevation*, or the *vertical plane*; the second, the *ground*, or *horizontal* plane. Both planes may be considered as perpendicular to each other, and the position of a point in space may be accurately determined by the intersection of the two perpendiculars erected from the projection of the point on the two planes. In *pl.* 4, *fig.* 20, AB is the vertical plane, and BC the horizontal plane; $a'b'$ is the vertical, and $a''b''$ the horizontal projection of a line. If we suppose lines to be drawn from the four points, perpendicular to their respective planes, a' and a'' will intersect each other in ab' and b'' in b, and the position of the points, a, b, in space will thus be determined. Now whenever

two points in any straight line are known, the line itself will be determined.

We can imagine the horizontal plane to be revolved about its axis in such a manner as to form an angle (= 2 R) with the other plane, leaving only one plane upon which objects are to be projected. If a line out of this plane is to be projected upon it, perpendiculars must be let fall from the two extremities upon the horizontal plane; the straight line connecting the feet of these perpendiculars is called the projection of the line.

As a straight line is determined by two of its points, and as curved lines require several, every curved line may be considered as consisting of infinitely small straight lines. The projection of a curved line, then, is the same as that of a straight line, only requiring more points in the line. Thus in *pl.* 4, *fig.* 23, let 1 2 3 4——9 indicate the position of a line in horizontal projection—we here suppose the horizontal plane to be revolved—and 1′ 2′ 3′——9′ be the position of the line with respect to the vertical plane *xy*; the projection of the line is now to be found. First of all a number of points is to be assumed in the line 1——9, the same determined in the line 1′——9′, and perpendiculars drawn to the corresponding plane, which determine the feet. Prolong these perpendiculars beyond their feet and they will intersect each other, the points of intersection of the corresponding perpendiculars forming the corresponding points of the projection. Thus, from the intersection of the perpendiculars 3 and 3′, the point 3^2 lying in the projection is ascertained. When all the points are found, the projection will be obtained by joining 1^2, 2^2, 3^2——9^2, this will be the line.

As surfaces are bounded by lines, we can obtain the projection of surfaces by finding the lines inclosing them. In *fig.* 21 let *abcd* be the position of a surface in plan, a^3 c^3 is the position of *ac* in elevation. To determine the two corners b^3 and d^3 on this line, project *b* and *d* upon *ac*, in b^2 and d^2, and take off these points on a^3 c^3. Drawing perpendiculars from the four extremities of the two horizontal figures, we shall have the points *a*′, *b*′, *c*′, *d*′ as the corners of the projection, which is itself obtained by connecting the corners by straight lines.

If the figure be bounded by curved lines, a mode of proceeding similar to that employed in the case of straight lines will be necessary. In *fig.* 22 let *ab* be the view of a circular plane, in ground plan, f^5 f^4, the same in elevation. It is well known that the end view of a circle perpendicular to a plane appears as a straight line, this in the ground plan being the horizontal, and in the elevation the vertical diameter. We must thus, first of all, find the points in the curved line which are to be projected. For this purpose describe the two semicircles, divide them into an equal number of equal parts, for instance, in *c*′, *d*′, *e*′, &c., and in a^4, c^4, d^4, &c., and project these upon the diameter; we shall thus obtain the points *a*, *c*, *d*, &c., and a^5, c^5, d^5, &c. By drawing the lines of projection from the like named points, we shall obtain the projected points of half the curved line. Thus, for instance, from the lines of projection from *d* and d^5, we get the point d^3, and as *d* and *h* lie at an equal distance from the centre, we obtain by means of the lines from *h* and a^5 the point h^3 symmetrical with d^3. After the

points of projection of the upper semicircle have been found, we describe the semi-curve a^2c^3——b^2, and corresponding to it, the symmetrical half, lying beneath.

Solids are bounded by surfaces, as these are by lines; the problem of finding the projection of a solid resolves itself, then, into finding the projection of points. In illustration of this, we will explain the method of projecting a regular six-sided pyramid, in its various positions. *Pl.* 4, *fig.* 24, exhibits this pyramid in its regular position, in a horizontal and vertical plane: *acdbef* is the polygon forming the base of the pyramid, and which we have placed in the same position in the ground plan, with respect to the bases *xy*, that the pyramid is to have in elevation. If we suppose the pyramid to be completed above this base, we shall have a *view from above* of the former. For this purpose, if the pyramid be right, we find the centre of the polygon: this will be the projection of the apex *g* of the pyramid. Lines drawn from the point *g* to the corners of the base, form the projections of the edges of the pyramid. To the eye, however, the projection thus obtained will suit for any height of the pyramid, as the point *g* is not determined with respect to its distance from the base; we must therefore have a side view of the pyramid, since, as already mentioned, two projections, at least, are necessary to determine the position of a point. As the lines which stand perpendicularly to the ground plane are projected as points, under the same conditions surfaces will be projected as lines. The case is the same with respect to the plane of elevation: *g* is the projection of the altitude of the pyramid in the plane, which appears as a line in elevation; *acdbef* is the projection of the base in plan, which appears in the plane of elevation as a series of lines, whose position and individual extremities are determined by drawing the perpendiculars *aa'*, *cc'*, &c. The position of the point *g'*, in the perpendicular *gg'*, is determined by the method already explained. By connecting the point *g'* with the points *a'*,*b'*——*f'*, we shall obtain the vertical projection of the pyramid.

Suppose that an oblique section, *h'n'*, be made through the pyramid, perpendicular to the plane of elevation, and its projection in the ground plane required; the first step will be to indicate the plane *h'n'* by a straight line. The lines *a'g'* and *ag*, *c'g'* and *cg*, &c., are corresponding projections. If, then, from the points where the plane *h'n'* cuts the different edges of the pyramid in the elevation, perpendiculars be let fall upon the corresponding edges of the plan, the points of intersection will determine the corners of the plane of intersection, *h*, *i*, *k*, *l*, *m*, *n*.

If we suppose the pyramid to rest with one corner, b^3, upon the basis *xy*, as in *fig.* 25, its axis, however, still parallel to the plane of projection, the projection on the horizontal plane must be changed, as the altitude of the pyramid is no longer perpendicular to this plane. To describe this projection, place the elevation obtained in *fig.* 24 upon the corner b^3, at the required angle, and then draw from the point *g* a perpendicular to the ground plan. From the point *g*, of *fig.* 24, draw a line parallel to the basis *xy*, until it cuts the perpendicular in g^2; then g^2 is the apex of the pyramid for the new projection. It is evident that the line gg^2 must be parallel to the basis

xy, as, according to the assumption, the axis of the pyramid remains parallel to the plane of elevation: the line gg^2 is the projection of the circular arc described by the apex g, during the supposed change of position about the corner b^3. The same condition holds good for all the other points of the pyramid; and by drawing perpendiculars from points a^3, b^3——f^3, their intersections with lines parallel to xy, drawn from a, b, c——f, will give the points a^2, b^2——f^2, determining the projection of the obliquely situated base: connecting these points with each other, and with the apex g^2, we obtain the horizontal projection of the oblique pyramid. In a similar manner we obtain the projection of the plane of intersection, h^3l^3, exhibited in the elevation as a straight line: this projection is h^2, l^2——n^2.

Let us now suppose the pyramid to be rotated upon the corner b^3, still at the same inclination to the base xy; the axis of the pyramid will no longer be parallel to the plane of elevation. It is evident that all points of the pyramid must describe horizontal arcs during this rotation, whose centres will lie in a perpendicular, supposed to be erected from the point b^2. Their perpendicular distance from the base must, consequently, remain the same as before. As, however, the inclination to the base remains the same, the projection in the ground plane needs to be changed only with respect of the direction of the edge g^2b^2 to the base xy. *Pl.* 4, *fig.* 26, represents the upper view seen in *fig.* 25, at the same angle with the basis xy. The preceding explanations have taught us that we can draw horizontal lines from all points of the elevation, in which the new projections of these points, for the new position, must lie. The points are absolutely defined, by drawing perpendiculars from the corresponding portions of the plan to these horizontal lines. Thus, to obtain the position of the point g^4 in the new projection, we draw the horizontal lines g^3g^4, and the perpendicular, g^2g^4. In like manner we obtain the projection of the base a^4, b^4——f^4, and consequently the projection of the entire pyramid, by uniting g^4 with these corners. As this pyramid is no longer parallel to the base, the plane of intersection, h^3l^3 (*fig.* 25), can no longer appear as a straight line in this last position of the pyramid. Its projection, h^4, l^4, k^4——n^4, is obtained by the preceding methods.

As an additional illustration, we give the projection of the three principal conic sections. If we imagine a plane to be passed through a cone, which is parallel neither to the axis nor to one of the sides, we shall obtain a regular, symmetrical, curved line, termed an *ellipse;* if the plane be passed parallel to one side of the cone, a *parabola* will be produced; and when parallel to the axis, a *hyperbola*. The development and properties of these three curves are cases of the higher Geometry and Analysis (see pages 24, 25). In this place we have to do only with their projections.

Pl. 4, *fig.* 27, is the projection of a right cone in the horizontal and vertical planes. The circle, A′B′, and the straight line, AB, are the projections on the vertical plane of the base, C is the apex, and DE the intersecting plane, appearing in elevation as a straight line, and whose intersection is to form the ellipse, whose shape in horizontal projection is to be obtained. The question reduces itself to finding the breadth of the ellipse for the different points of the circumference. These points lie symmetrically upon the

surface of the cone, only in different planes above the base; and it is necessary to find the projections of these planes in both views of the cone. In the vertical projection, these planes appear as straight lines; in the horizontal plane, as circles. When we pass planes through D and E, in the vertical projection, the points D and E, of the curve, will be situated in them; if, then, the length DE be divided into any number of equal parts, and horizontal planes be passed through the points of division, there will be two points of the ellipse in each plane, which will be situated in that part where the line DE cuts these planes in succession. To obtain the form of the ellipse in the horizontal projection, we draw in it the diameter, A′B′, and let fall upon it perpendiculars from the points 1. 2. . . . DE: the points 1′, 2′, &c., will answer to the horizontal projection of those points, and as the horizontal projections of the surfaces projected as straight lines in elevation must be circles, these can readily be determined, knowing their radii, C′, I′, &c., and their common centre, C. These circles are cut successively by the ellipse. By drawing the perpendiculars, DD′ and EE′, we obtain the projection of the extremities, since the axis of the ellipse lies parallel to the plane of projection. Drawing a perpendicular from the point where the ellipse cuts the plane marked 6, until it cuts the circle 6′ in the horizontal projection, we shall obtain one point of the horizontal projection of the ellipse, or two as the ellipse is symmetrical. By a repetition of the process, a number of points in the horizontal projection will be obtained, through which the ellipse itself may be passed. The figure standing near *fig.* 27, exhibits the actual view, or the orthographic projection of the ellipse. It is obtained by taking off the axis, DE, of the ellipse from the vertical projection, with its planes of intersection, which would here be represented as straight lines. From the horizontal projection, we obtain the true breadth, and if these be described one after the other upon the corresponding planes on each side of the axis, we shall obtain the points through which the ellipse is to pass.

Pl. 4, *fig.* 28, exhibits the vertical and horizontal projection of a right cone, with a parabolic intersection. DE is the projection of the parabola, which, for the vertical plane, is a straight line. The horizontal projection is obtained precisely as in the case of the ellipse. Thus, 1, 2, 3, — — — horizontal planes are passed through that part of the front view of the cone traversed by the parabola, at equal distances from each other; these appear as straight lines: they are circles in the horizontal view of the cone. In *fig.* 28, semicircles only are drawn. From the points, 1′, 2′, &c., where the planes passed through the elevation cut the parabola, draw perpendiculars to the horizontal projections of these planes; the perpendicular, DD′D″, will form the foot of the parabola, EE′ its vertex, and perpendiculars from 1′, 2′, — — — let fall upon the cirles 1^2, 2^2, 3^2, — — — will form intersections, all lying in one arm of the parabola, the other being easily constructed, as shown in *fig.* 28. The orthographic projection of the parabola is shown in the figure near *fig.* 28. It is obtained by erecting a perpendicular from the middle of DD′, and marking successively upon this the height D1′, D2′, D3′, &c., and drawing throngh these points, parallels to

DD′. Marking off on these horizontal lines, the breadths taken at the corresponding parts of the horizontal projection of the parabola, we shall obtain the points, 1′, 2′, 3′, 4′, and 5′ E, which determine one half of the parabola. The other half is to be drawn symmetrically with this.

A simple method of describing a parabola, when its breadth below and its altitude to the vertex are given, is shown in *fig.* 31. At the middle of the line AB, erect the perpendicular, CD=twice the height of the parabola, and determine the vertex, C; through this *xy* is passed, parallel to AB. At A erect the perpendicular, A*x*, and divide it in *f*, *g*, *h*, &c., into equal parts, which are then marked off from D, at *a*, *b*, *c*, &c. From C to *k*, and from A to *a*, draw straight lines; their intersection will give one point of the parabola. Another point will be obtained by the lines C*i* and A*b*, &c. The second limb of the parabola, being symmetrical with the first, is easily constructed.

The projection of the third conic section, the *hyperbola*, is explained by means of *fig.* 30. As this is perpendicular to the base, it can appear only as a straight line in horizontal projection, this line being D′F′. The vertex is projected at E′. If the line E′F′ were also perpendicular to the base line, the hyperbola would be projected on the vertical plane in another straight line: this is the case in *fig.* 55, with respect to the line CA. As this view can give no satisfactory representation, we have in *fig.* 30 made the plane of intersection parallel to the vertical plane. To determine the vertex of the hyperbola in the vertical view, we first draw the axis, CC′, take off from C, and parallel to the base, the distance C′E′, and let fall from the point thus obtained, a perpendicular to the side of the cone. From the point where this meets the side, draw to the axis a parallel to the base; this determines the point E on the latter. Place any number of planes of intersection, in the horizontal projection, parallel to the base; these will form circles with the common centre C′, and whose vertical projections as straight lines may be readily ascertained by methods already explained. From the points 1, 2, 3, &c., of the ground plane, where the projections of the intersecting surfaces cut those of the hyperbola, draw perpendiculars to the corresponding vertical projections of the aforesaid planes of intersection; we thus obtain the intersections 1′, 2′, &c., as points of the hyperbola, which may then be joined by a line continuous with the vertex E. Another method of describing the hyperbola is presented in *pl.* 4, *fig.* 29.

If one body penetrate another, a surface of intersection or penetration will be formed. It is one of the problems of projection to determine the outlines of such surfaces of intersection, and their projections under different circumstances. The number of possible cases is infinite, and we can here only adduce a few as examples. In *fig.* 32, two cylinders are shown, of unequal diameters, and penetrating each other at right angles. The base line, or the one in which the surfaces of horizontal and vertical projection intersect each other, may be represented by *xy*. The one cylinder is represented in vertical projection as circle E, and in horizontal projection as rectangle AB; the other, being parallel to both planes, is in both cases

exhibited as a rectangle, until it touches the second cylinder; the problem, therefore, is reduced to finding the part which intersects the surface of the first cylinder. In vertical projection this is easy, as here the line of intersection coincides with the convexity of the cylinder; nothing more is necessary, then, than to prolong the corners *a* and *g* to the cylinder E. The case is different, however, in the horizontal projection, the line of intersection here being a curve. If the axes of the two cylinders lie in the same plane, the curve will be symmetrical; if, as in our example, this is not the case, the superior half will be different from the inferior, and it becomes necessary in all cases to seek similarly situated points of the intersection surface, in the horizontal and vertical projection. For this purpose, under *ag* and *a'g'*, describe the semicircles whose projections are the lines *ag* and *a'g'*; divide their circumferences into any number of equal parts, and draw lines parallel to the edges of the small cylinder. These must reach to the circumference of the larger cylinder, in the vertical projection, and may be of any length in the horizontal. From the points where these lines intersect the circumference of the larger cylinder in the vertical projection, let fall perpendiculars upon the corresponding parallels in the horizontal projection. We shall thus obtain the points *h, i, k, l, m, n,* and *o,* which are common to the convexities of both cylinders, and must consequently lie in the contour of the surface of intersection; this latter may then be easily described. We have represented the lower half of the curve; the upper is obtained in a similar manner. As the cylinders approach towards equality in thickness, the curve becomes abrupt; when both are equal, the intersection appears in the projection as two straight lines, which meet above the axis of the cylinder.

Pl. 4, *fig.* 33, represents the intersections of two cylinders, of different diameters, when their axes lie in the same plane. The mode of constructing the cylinders and their bases follows from what has already been said. We must remark, however, that the two upper ellipses in the vertical view have arisen from a misapprehension of the engraver; the upper bases should have been projected as straight lines. The construction of the intersection follows from what was said in explanation of *fig.* 32. With respect to the horizontal projection, the views of the bases are readily found, these being ellipses, whose perpendicular axes are the respective diameters of the cylinders, the horizontal being determined from the vertical view, by means of the perpendiculars *gg'*, *hh'*, *ee'*, *ff'*, *aa'*, *bb'*, *cc'*, & *dd'*. To project the line of intersection, the points of division of the projection *e'f'* are projected upon the ellipse *ef*, at 1', 2', &c., parallels to the surface, drawn through the points of the ellipse thus obtained, and at the corresponding points the line of intersection in the vertical view, cut by perpendiculars. The points of intersection will be common to both cylinders, or be points in the line of intersection. The lower line of intersection, dotted only in the figure, is obtained in a similar manner.

Fig. 34 exhibits the intersection of a cylinder and a sphere, where the cylinder has the smaller diameter of the two, and is not parallel to the surface of projection. The development of both projections presents no difficulty in itself, if what has already been said on the subject be kept in mind;

it is only the circumferences of the surfaces of intersection that require to be attended to here. These surfaces of intersection must, in all cases, be curves: they are obtained by dividing the circumference of the cylinder into any number of equal parts, and, through these, drawing parallels to the sides of the cylinder. The figure represents only a few of these parallels. Where these lines intersect the perpendicular diameter of the sphere, in the vertical view, planes of intersection are to be passed through the sphere. These can be very readily transferred to the horizontal view, where they appear as circles. The points where the parallels to the circumference of the cylinder intersect the corresponding circular sections, are points of the surface of intersection, which may then be readily described. On account of the small scale of our figure, only a few points have been determined; the rest are readily formed in the same manner. A concluding example of the intersection of bodies is presented in *fig.* 35. Here, an oblique cone penetrates an oblique cylinder, in such a manner that part of the cone passes through the cylinder. To develope the intersection, the method employed in reference to *fig.* 33 must be again brought into play, with this difference only, that the lines drawn from the points of division of the base to the cone must not be parallel to the lateral edges, but converging to the apex of the cone.

b. The Reticulations of Bodies, and the Unfolding or Development of Surfaces.

By the reticulation of a body is meant the continuous description of its inclosing surfaces in one plane. This is easiest in bodies which are inclosed entirely by plane surfaces, as is the case in the so-called regular bodies. It is only in this case that the reticulation of a body can exhibit a perfectly true picture of its surface. *Plate* 4, *fig.* 49, is the reticulation of a tetrahedron, formed by four equal equilateral triangles; *fig.* 50, that of a cube, or hexahedron, formed by six equal squares; *fig.* 51, that of a dodecahedron, formed by twelve equal regular polygons; *fig.* 52, that of an icosahedron. The figure is not quite complete, as in addition to the fourteen equal equilateral triangles, six more must be added, viz. one in the upper row, next to 11, three in the middle row, next to 7, and two in the lower row, next to 14.

In conclusion, we will present one or two examples, in which not the entire reticulation, but merely the convex surface, will be referred to. The bottoms, so to speak, are very easily constructed.

Fig. 53 represents, at A, the horizontal intersection of a cylinder by the plane CD, this latter being itself visible in *fig.* 54. Let portions be cut off obliquely from the lower part of the cylinder, by the lines BC and BE, and an oblique portion from the upper part by the lines FG. Suppose, now, that half the convex surface of this remnant of the cylinder is to be ascertained. If the cylinder had not been mutilated in this manner, its development would be a rectangle, the altitude being equal to the height, and the base equal to the circumferenee of the cylinder, or, as in our illustration, to half

this circumference. This rectangle must, in fact, be constructed upon the elements first mentioned. The semi-circumference, in *fig.* 53, is to be divided into 8 equal parts, as shown at *a*, *b*, *c*, *d*, &c.: these must be so small that, without material error, the arcs may be considered as straight lines. These eight parts are to be transferred to the rectangle at a^2, b^2, &c., and the perpendiculars a^2a^3, b^2b^3,— — — i^2i^3, drawn, which will all lie in the convex surface of the cylinder. From the points *a*, *b*, *c*, — — — *i*, in the horizontal projection of the cylinder, lines are to be drawn until they intersect the oblique section of the cylinder at *a'*, *b'*,— — *i'*. From the points *a'*, *b'*,— — — *i'*, draw parallels to the base, *xy*, until they intersect their corresponding lines; the points a^3, b^3, c^3, — — — i^3, will thus be obtained, which may be connected by a curve. This will be the development of half the ellipse of which the line FG represents the vertical projection. The perpendiculars *aa'*, *bb'*, — — — *ii'*, also intersect the projections CB and BE of the semi-ellipses of the lower cylinder sections; accordingly, here, as in the upper ellipse, the corresponding points may be connected by parallels to the base, *xy*, and points of the curve obtained on the lines a^2a^3, b^2b^3,— — — i^2i^3. *Fig.* 54 represents rather more than half the development of the cylinder.

Fig. 55 exhibits the horizontal and vertical projection of a right cone, intersected in the three conic sections, and projected according to the rules given for *figs.* 27, 28, 29. The convex surface of this cone is now to be found, and upon it the developments of the three conic sections, described.

The convex surface of a right cone is a circular sector, whose radius equals the slant height of the cone, and whose arc equals the circumference of the base. If, then, from any point, with a radius equal to the slant height of the cone, an arc, x^2y^2 (*fig.* 56), be described, this sector, with its two radii, will determine the convex surface of the cone, provided that the proper length of the arc has been obtained. This may be done by dividing the circle whose projection is *xy* (*fig.* 55), just as was done in the case of *fig.* 53, and transferring the arcs of division. The sum of these arcs, which will be few or many as the result is to be less or more accurate, will determine the extent of the circumference of the base. Lines drawn from the individual points of division to the centre, in *fig.* 56, will represent so many lines of the convex surface of the cone. Their projections in elevation (*fig.* 55) will be obtained by transferring the parts from the plan, *x'y'*, of the base, to its vertical projection, *xy*, by means of perpendiculars. Lines must then be drawn from the points of intersection thus obtained, to the apex. These will intersect the vertical projections of the conic sections.

From the vertex, in *fig.* 56, lay off on the middle line the distance from the apex of the cone (*fig.* 55), to the point G'; G' will then be a point in the development of the ellipse. The distance from the apex of the cone (*fig.* 55) to the first intersection of the ellipse by the projection of the sides of the cone in *fig.* 55, laid off on both sides of the point G^2 in *fig.* 56, gives two new points in the development of the ellipse; and the same is to be done with respect to the remaining lateral lines of *fig.* 55. Connecting these points in *fig.* 56, will give the development of the ellipse. In like manner the curve $B^2A^2C^2$ is found, as the projection of the hyperbola The

parabola, in its development, appears divided into two symmetrical parts, owing to its falling on the line in which the convex surface of the cone is supposed to be divided. By these various constructions, we obtain the symmetrical figure, $H^2E^2F^2B^2C^2A^2D^2E^2H^2G^2$, which forms that part of the convex surface of the cone bounded by the three conic sections.

B. PROJECTION OF SHADOWS.

By projection of shadows is to be understood the method of representing bodies as they appear to an observer under illumination from a certain direction. It is evident that both the direction and the nature of the illumination (whether from a point or a surface) must greatly influence this mode of representing objects. If the illumination be supposed to proceed from a single point, it involves a department of the subject which will not be treated of in this place, as it more properly belongs to another part of our work. We here treat only of that description of shadows produced by an infinitely great luminous surface, considered as the source of light. In the former case, the rays of light form a cone, and diverge the more the nearer the source of light (the apex of the cone) lies to the object illuminated. In the latter case, and the one to be now treated of, the rays are all parallel to each other. In what follows, we suppose the plane of illumination to be so situated with respect to the surface of representation, as that all the rays come in the direction of the diagonal of a cube, i. e. incident at an angle of 45° on both the horizontal and vertical plane. The rays of light are supposed to come over the left shoulder, and to fall upon the paper and the object to be represented.

The general head of shadows embraces two subdivisions, viz. *shadows* proper and *shades*. The *shade* of a body is that part of its own surface from which light has been intercepted by some other part of the body itself. The *shadow of* a body is that part of indefinite space from which light is excluded by the body. The *shadow on* a body is that portion of its surface from which light has been intercepted by some other body, placed between it and the source of light.

With respect to the shades of bodies, it is evident that the rays of light can exert their greatest powers of illumination only when they fall at right angles upon a surface, and that the illumination will be less, the more oblique the angle of incidence. The deepest shade must be produced where the rays are only tangent to the body, as they there no longer illuminate the body. Taking for illustration a half cylinder, as exhibited in horizontal projection in *pl.* 4, *fig.* 38, the line bb' will be perpendicular to the surface, and the illumination of the cylinder will consequently be greatest in this part. This is the point of *highest light.* The ray of light dd' will only be tangent to the circumference of the cylinder: here then will be the *darkest shade.* Between b' and d the rays of light will fall more and more obliquely, and the illumination become less and less. The same must be the case from b' towards a. Beyond d the body would be entirely dark, were it not for

the reflection of light from other bodies about or beyond this. The body will therefore become again somewhat lighter, after its darkest shade. Similar conditions must be presented in respect to the illumination of all other surfaces, and it will not be difficult to determine the tone of light of each surface, knowing the direction of the incident rays. It is evident that by taking this direction at other angles, any other illumination may be constructed. It must not be forgotten, however, that the angles of incidence upon the two planes of projection must always be complements of each other, so that light, incident at an angle of 40° upon the plane of elevation, will strike the horizontal plane at an angle of 50°, &c.

Shadows, as already mentioned, are produced when one part of a body projects beyond another, or one body is interposed between the source of light and another body. These shadows, like the bodies themselves, may be constructed when the measurements of all the parts are known, *i. e.* the body itself, with all its accompaniments, may be constructed in plan and elevation. The rules for the reception of light must always be the same as in the case of shades, and the same angle of incidence of the light must be employed for both the shades and the shadows.

When a shadow is to be determined, it is, first of all, necessary to determine the lines which cast the shadow; and after these have been found, to seek the projections of these lines of shadow. After this, those parts of the entire surface from which light is intercepted may be readily determined.

a. Shades and Shadows upon Plane Surfaces and Curved Surfaces of Elevation.

Let us suppose *figs.* 36——44, *pl.* 4, to represent the vertical, and beneath this the horizontal projection of a plane wall, to whose anterior face six bodies, of different forms, are attached, and covered above with partly circular, partly rectilineal plates: let now the problem be, to determine the shadows cast by the plates upon the solids, and by both plates and solids upon the wall.

Fig. 36 is a four-sided prism, A, covered with a somewhat projecting plate, B, likewise four-sided. To find the various shadows, it becomes necessary first to find the line of shadow. The direction of the rays of light is here, and in the following cases, assumed at 45°, for the horizontal and vertical projection. Draw lines in the horizontal projection, in the direction of the rays, to the bodies A′ and B′; then the first rays passing by the body will go through the points *c* and *d*. These are the projections of the two right edges of the bodies A and B, in vertical projection; the latter will therefore be two lines of shadow. If, moreover, rays be drawn at an angle of 45° in the vertical projection, one will pass by at a' and others at c^2, d^2, d^3: the line $a'd^2$ will consequently cast a shadow. As c^2 is the projection of the upper right hand edge of the prism, d^2 that of the lower right hand edge of the plate, and d^3 of the upper right hand edge of the same, the four lines just mentioned will cast shadows. Of all these edges, the line $a'd^2$

alone casts a shadow upon A; all the rest, and even a part of $a'd^2$, cast shadows upon the wall only.

As the direction of every line is determined by several points lying in it, to determine the boundary of shadow in both projections, we need two points for a straight line, and a greater number for curves.

The shadow of the line $a'd^4$ falls upon the body A, and it becomes necessary to obtain the point b^2, from which the shadow must run parallel to the shadow-casting edge, the two surfaces of the body and the plate being parallel. In any case, the point which casts its shadow upon b^2 must lie in the line $a'd^2$, whose horizontal projection is ad, and this, in a direction of 45°. If, therefore, in the horizontal projection, a line be drawn from the left corner of A′ to ad, at an angle of 45°, it will determine b as a shadow-casting point. This point is then transferred to the vertical projection, by means of the perpendicular bb', and b' is then exhibited as the shadow-casting point in the latter. Drawing a line from b', at an angle of 45°, its intersection with the left edge, b^2, of the prism determines the shadow of the point b', and the direction of the line of shadow. As the line $a'd^2$ determines the boundary of the surface which prevents the incidence of light upon the body, A, that part of A above the line passing through b^2, lies in the shadowed portion.

With respect to the shadows cast by the prism and plate upon the wall, the edge a casts a shadow, which necessarily begins in the point where this edge touches the wall. Drawing a line from a', at an angle of 45°, this line, $a'a^2$, will be the line of shadow. The side of the plate behind the line d^2d^3 will likewise cast a shadow, whose direction is determined by the two lines drawn at an angle of 45°, in the vertical projection. The length of this shadow is obtained by considering that the point d, the horizontal projection of the line d^2d^3, and consequently the edge which is projected through it, casts its shadow to d'. The edge $a'd^2$ also casts a shadow upon the wall, which must run parallel to the edge, the edge and the wall being themselves parallel. The point d^4 is the point of shadow for d^2; if then, through d^4, a parallel to $a'd^2$ be drawn, this will be the line of shadow of the plate on the wall behind it. Finally, the side of the prism lying behind c casts also a shadow upon the wall, whose limits will be the shadow of the edge which is projected through c. If then the tangential ray cc' be drawn, and the point c' be projected on the vertical plane, the perpendicular through this point will determine the line of shadow, whose upper point still remains to be determined. The point c^2 in the vertical projection answers to c in the horizontal; then, if we draw a line, at an angle of 45°, through c^2, it will intersect the above mentioned perpendicular in e, and this point, e, will be the shadow of c, or, what is the same, of c^2, and will limit the shadow of the edge of the prism.

Pl. 4, *fig.* 37, exhibits the half of a hexagonal prism, covered by a four-sided plate, under the same conditions as in the preceding case. The shade of the body is found according to the principles already laid down. The surface receives the strongest light to the left, the rays here falling perpendicularly; the light, however, fades somewhat towards the extreme left.

The anterior surface receives the light more obliquely, and thus appears somewhat darker and uniformly illuminated, the surface being parallel to the plane of projection. The light passes entirely by the right surface, which consequently appears entirely dark, brightening a little, however, towards the wall, where it receives a certain amount of reflected light. The shadows on the wall are constructed as in *fig.* 36; those cast by the plate on the body, are obtained as follows: that for the anterior surface is obtained, as in *fig.* 36, by the lines bb', b^2b^3, as this surface is parallel to the surface of representation, and to the anterior surface of the incumbent plate. The shadow cast by the corner a of the plate, will be determined by a ray of light passed through the point. It will fall upon the left lateral surface at a^2, which will therefore be the projection of this shadow. To obtain this point in vertical projection, draw the perpendicular a^2a^3, and intersect this by a ray through a, a^3 will be the point desired. If this be connected with the extremity of the shadow or the anterior surface, the broken line through a^3b^3, gives the shadow of the anterior face of the plate. Since a is the projection of the horizontal lateral edge of the plate, it follows that every ray through that edge must be parallel to aa^3; the direction of the shadow, therefore, from a^3 towards the left, will be regulated by that of the ray.

Fig. 38 represents a half cylinder, covered by a four-cornered plate. The shade of the body is obtained by drawing a line from the left-hand side to the centre, at an angle of 45°. Where this line cuts the convex surface of the cylinder, the light will be greatest, the rays falling here in a plane perpendicular to the surface. A second ray, tangent to the surface, determines the line of deepest shade, up to which the light decreases more and more, and beyond which reflected light comes into play. The shadows of the body and the plate on the wall are obtained as before. The shadow cast by the plate on the body must be a curve, the body itself being curved. To obtain this shadow, find first the shadow of the point b, the corner of the plate, which is done by means of the lines bb', b^2b^3. As it is a curve that we are seeking, it will be necessary to obtain a number of points in it, so as to determine its direction. The points casting shadows lie, however, in the line be. One of the points of shadow is given by the line cc', c^2c^3, and as many more can be obtained as is necessary for the required degree of accuracy. The shadow naturally ceases where the ray, dd', is tangent to the cylinder: the shadow then passes into the shade of the body. To find the direction of the shadow from b^3 to the left, seek first the shadow of the point a. This falls at a', and the vertical projection of this point must lie on the line a^3. But b^2 is the projection of the left side of the plate; the point a^3 lies, therefore, behind b^2, and if a ray be passed through b^2 (actually through d^2), it will determine the point a^2. This lies in the line b^2b^3, and all the other points of the shadows cast by the lateral edge will fall in the direction b^2b^3.

Pl. 4, *fig.* 39, represents the half of a hexagonal prism, covered by a semicircular plate. The shade of the body has been already constructed in *fig.* 37, as well as the shadow of the body. It now remains to determine the shadow of the plate on the wall. As the plate is circular, its shadow must

be a curve. The method of finding this curve is easily determinable from the preceding considerations. Take a certain number of points in the horizontal projection, obtain their shadows in this projection, and transfer them to the vertical projection. Thus, the point c will cast its shadow to c', and this must lie on the perpendicular line, $c'c^3$, of the vertical projection; transfer the point c to c^2, and from this point draw the ray c^2c^3; we thus obtain the projection of the point of shadow; and after a sufficient number of points has been obtained, an indication of the curve of shadow produced by the lower edge of the plate. As the upper edge must cast a similar shadow, this is to be obtained in the same way. The point d^3 determines the extreme point of this curve, which is closed by a perpendicular representing the shadow of the vertical edge or line of shade of the plate. The shadow of the plate upon the prism must also be curved, as it falls from a curved upon a plane surface. First of all, it is necessary to find the point of shadow upon the edge. For this purpose, draw the line aa' in horizontal projection; we shall thus obtain the shadow-casting point, a^2, in the vertical projection, and a^3 as the point of shadow. According to the method described in *fig.* 38, the points b^3, c^3, &c., are then obtained, and consequently the curve of shadow upon that side of the prism which lies in the light.

Fig. 40 exhibits the half of a truncated cone, covered by a four-sided plate. The construction of the shade of the body, and the shadow of the cone and plate upon the wall, differs very little from what has been described in *fig.* 38; it is different, however, with respect to the shadow on the cone. This shadow is analogous to that of the cylinder; as, however, the surface of the cone is not perpendicular, but deviates every moment from the perpendicular, its shadow must fall somewhat differently. To obtain this shadow, suppose several horizontal planes to be passed through the vertical projection of the cone, appearing in it as straight lines, and in the horizontal projection as semicircles; they are indicated by the figures 1, 2, 3, &c. Suppose the rays necessary for producing the shadow to be drawn in the horizontal projection, they will intersect the cone, and as the sections are parallel to the axis of the cone, these sections will appear in the vertical projection as hyperbolas, or at least parts of such, and may be constructed according to *fig.* 30. These hyperbolas serve instead of the perpendiculars employed in *fig.* 38, and by means of them, and of the projections of rays as bb', b^2b^3, the curve of the shadow may be very readily determined.

Fig. 41 represents a half cylinder, covered by a semicircular plate. Here one plane casts a shadow upon another parallel to it; the shadow will therefore be parallel to the shadow-casting line, and to determine this shadow nothing more is necessary than to pass a ray through the corner where the shadow begins. From the point where this ray intersects the edge of the cylinder, draw a line parallel to the plate: this will be the line of shadow.

Innumerable cases might be adduced, but the general principles involved in all are nearly such as have been explained and illustrated in the preceding instances.

b. Shades and Shadows upon hollow, straight, and curved Surfaces.

Fig. 42 exhibits a four-cornered niche, closed above. The point a is the horizontal projection of the shadow-casting line, and must itself be the shadow-casting point. Passing a ray, aa', through this point, it will determine the situation of the point of shadow upon the back wall, whose projection in elevation may be determined by the lines $a'a^3$, and a^3a^2 at a^3. As, however, a is the projection of the entire shadow-casting edge, the limit of shadow for this edge must lie in the perpendicular $a'a^3$; a parallel, therefore, to the corner of the niche, drawn through a^3, will determine the shadow of the cover.

Fig. 43 represents a niche, forming the half of a hexagon, and covered rectilineally above. The ray of light, aa', determines the extremity of the shadow in horizontal projection. The intersection of the perpendicular $a'a^3$, with the ray through a^2, determines its position, a^3, in elevation. The part of the perpendicular below this point, a^3, will be the line of shadow cast by the vertical edge of the niche. As the right side of the niche is oblique to the surface of representation, the shadow must run obliquely from d^3; now, as the cover coincides with the edge of the niche in c, the shadow must run in this direction; d^3c will therefore be the line of shadow on this oblique side.

Fig. 44 exhibits the half of a hollow cylinder, open above, and the problem is, to find the shadow cast by the edge of the cylinder upon its inner surface. Its boundary in vertical projection is obtained, in the first place, by passing a ray through the point a, the horizontal projection of the edge of the cylinder. The vertical projection of the point a', where it meets the inner surface of the cylinder, is obtained at a^3, by the intersections of the lines $a'a^3$ and a^2a^3. A part of the upper edge of the cylinder also casts a shadow. This begins in the point c^2, which is the vertical projection of the point c', where a ray is tangent to the surface of the cylinder. The point c' is obtained by drawing a line from c to the surface of the cylinder, at an angle of 45°. The shadow runs from c^2 to a^3 in the curve. This curve is found by obtaining individual points, as before explained.

Pl. 4, *fig.* 45, exhibits the shadow of a straight cover to a semi-cylindrical niche. The straight part of the shadow is obtained as in the preceding case; the figure itself shows the method of finding the shadow of the covering. Thus for instance, the shadow of the point b is obtained by means of the lines bb', b^2, and b^3, and the shadow ends in the point c', where the anterior edge, a^2c', of the covering, meets the wall of the cylinder.

Fig. 46 explains the method of finding the shadow cast upon its inner surface by the edge of a niche, dome-shaped above. This shadow has a very peculiar outline, and can only be determined for the dome by a very exact projection of the rays, and the accompanying subsidiary lines. The limit of the straight part of the shadow is easily found to lie at a, according to *fig.* 45; the extremity of the compound shadow must necessarily lie at e, where a ray of light would be tangent to the dome. To obtain the curve between a and e the following method is to be employed, which is quite

analogous to those already mentioned, and peculiar only in the construction of the perpendiculars, by means of which the vertical projection of those points is found, whose horizontal projection has already been ascertained. These perpendiculars, which in all the other constructions have appeared as straight lines, here present themselves, in the space of the dome, as curves. To determine this curvature, horizontal sections are passed through the vertical projection, at 1, 2, 3, &c., projected as straight lines here, but as semicircles in the horizontal view. Suppose in the ground-plan a ray to be passed from any point in the anterior edge of the dome, against the inner wall; this will intersect the projections of all the above mentioned horizontal projections. It will then be easy to determine, from the preceding observations, the vertical projections of these intersection lines, which will be straight to the commencement of the dome, and will then curve according to the curvature of the dome. If these lines be intersected by a line, at an angle of 45°, from the vertical projection of the point from which the ray has been drawn in the horizontal projection, we shall obtain one point in the curve of shadow; the other points necessary fully to determine this curve, may be obtained in the same manner.

Fig. 47 teaches the method of finding the shadow cast upon the inner wall of a dome-shaped, closed, half-round niche, where a part of the dome is cut away above, and the niche continued in a semi-cylinder. This is a combination of the cases treated in *figs.* 44 and 46, so that it would merely be necessary to construct two shadows, one after another, but for the fact that a part of the dome (that lying between b' and c'), has been cut out. Here it is not the contour of the dome that casts the shadow, but the boundary of the section. In this manner a part of the shadow seen in *fig.* 46 is cut away, as shown in *fig.* 47.

It is necessary, before concluding these remarks on shades and shadows, to advert to the cases where the body is not attached to a wall, but stands at some distance from it. Although these cases present now no difficulty whatever, it may be advisable to give an example, as in *fig.* 48. Let a six-sided prism stand in front of a wall, as shown by the horizontal projection of *fig.* 48. The problem is, to ascertain the shadow cast by the pyramid, in horizontal projection upon the floor, and in vertical projection upon the wall behind. First, to find the point where the apex g casts its shadow. Draw rays from g and g', in horizontal and vertical projection, and combining them in the usual way, find their intersection at g^3, the vertical plane. The line $g'g^3$ is the projection of the shadow of the axis of the prism, and g' is a point in this shadow. We obtain the shadow-casting point of the axis by drawing a line to that axis, from g', at an angle of 45°. If a horizontal plane, d^2b^2, be passed through g^4, this plane will be projected in plan as a small hexagon. Pass tangent rays to this hexagon; they will determine the points d' and b' as the projections of the shadow-casting points of the pyramid, in horizontal projection. If then from d and b the lines dd' and bb' be drawn, these will determine the outline of the tapering shadow of the pyramid. The lines $d'g^3$ and $b'g^3$ will determine the outline of the

shadow in the vertical view, as is clearly shown by drawing the rays d^2d and b^2b'.

C. Linear Perspective.

We shall here confine ourselves to the mathematical principles of perspective, as occasion will be had to speak of perspective in general and its application to the arts, in another part of the work.

We have already remarked, in the introduction to projection, that in perspective the visual rays are all supposed to proceed from one point—the point of sight; while in projection they are supposed to be parallel to each other. We may here again employ the illustration of the plate of glass interposed between the spectator and the object, and upon which the perspective image of the latter is represented.

In *fig.* 57, *pl.* 4, let XY be the ground plan upon which a square, *abcd*, is supposed to be drawn, and whose perspective representation is to be obtained on the vertical glass plate RS. Let F be the station of the observer, and A the point from which he sees the square *abcd*. This point is called the *point of sight.* The distance of the observer from the glass plate—the plane of projection or the plane of the picture—is determined by the line AA′; the point A′ is called the *point of distance.* If visual rays be drawn from the point of sight to all the corners of the square *abcd*, these must necessarily intersect the glass plate or the plane of the picture. It is then necessary to find the points of intersection, so that by joining them by straight lines the perspective of the square may be obtained. For this purpose, in the horizontal plane draw perpendiculars through the points *a*, *b*, *c*, *d*, extending to the foot of the glass plate. In the position of the square here assumed, two such lines are all that is necessary, as two of the corners lie in one line. Drawing lines from *f* and *g* to A′, these must lie in the plane of the picture, and the same must be the case with their intersections with the visual rays. The points *a′*, *b′*, *c′*, *d′* will then be the perspective representation of *a*, *b*, *c*, *d*, the corners of the square. By properly connecting the points *a′*, *b′*, *c′*, *d′*, by straight lines, the quadrilateral thus obtained will be the perspective of the square.

The line DD′ supposed to be drawn at a height equal to that of the point of sight A, is called the horizon of the picture: it is the principal line in a picture, as by its height all the parts of the picture are regulated. All visual rays tend to the point of sight, and lines perpendicular to the plane of the picture will have their perspectives all tending to the point of sight. The point of sight is also called the *vanishing point*, because in it the lines appear to vanish. Other parallels not perpendicular to the plane of the picture meet in the horizon, but not in the point of sight. There may, therefore, be several vanishing points in the same picture, but only one point of sight, since an object for one and the same picture can only be observed from a single point.

The preceding construction, however satisfactorily it illustrates the principles of perspective, is yet too complicated in practice; simpler constructions therefore become necessary.

Fig. 58 exhibits a simplified construction for representing the square just mentioned. Let *xy* again be the basis of the plane of the picture, lying then above this line; the space below *xy* is the ground plane upon which the square *abcd* is described, and which rests immediately against the basis. We assume for the first case that the point of sight A is opposite to the middle of the square, and that DD′ is the horizontal line. The distance of the point A from the plane of the picture or the perspective plane must be given in numbers or otherwise, and laid off right and left from the visual point on the horizon; D and D are then the two points of distance. From all points of the square draw perpendiculars to the base, meeting it in *a* and *b*, from which points, rays, as *a*A, *b*A, are to be drawn to the visual point. The lines *a*D and *b*D are also to be drawn from the points *a* and *b* to the points of distance D and D opposite to them; they will intersect those first drawn in *e* and *f*. By connecting the points of intersection thus obtained by straight lines, we shall obtain the figure *abef* as the perspective of the square *abcd*, for the situation of the visual point at A. If the visual point be not in the middle, but at A′ for instance, the points of distance will lie at D′ and D′: visual rays from *a* and *b* to A′ willi ntersect the lines *a*D′ and *b*D′, and thus determine *abgh* as the perspective of the square. It must be remarked that two points of distance are not always necessary, one being sufficient in most cases, as will be shown in the next example.

If the square *abcd* does not lie immediately against the basis, as in *fig.* 60, the process is somewhat different, as the distance from the basis is to be taken into account. In this case let D be the point of sight, and A the point of distance, and draw perpendiculars to the basis from the four corners. These lie here in two lines, as the square is parallel to the basis. From the points where these perpendiculars meet the basis, draw lines to the point of sight D. Take off the distance of the corners from the basis, in the direction opposite to the point of distance D; for the point *a* we obtain *a′*; for *b*, *b′*; for *c*, *b′*; and for *d*, *d′*. Drawing lines from *a′*, *b′*, and *d′* to the point of distance A, they will intersect those drawn to the point of sight in a^2, b^2, c^2, d^2; connecting the four corners a^2, b^2, c^2, d^2 by straight lines, we shall have the perspective picture of the square at its proper distance from the basis.

From this figure we perceive that all lines in the object which run parallel to the basis, must be parallel to it in the perspective representation.

Pl. 4, *fig.* 59, exhibits a complicated rectilineal figure, with the construction of its perspective representation. The mode of operation is precisely the same as in the instance just explained.

Fig. 61 shows how a curve is to be represented in perspective. The curve is here a circle, *ab*; A is the point of sight, and D the point of distance. Here it is necessary to determine the perspective of several points, through

which the curve is then to be passed. Divide the circle into any number of equal parts, the number being greater with the size of the circle and the degree of accuracy required. From the points of division draw perpendiculars to the basis. As two of these points lie exactly behind two others, we shall have only five points on the basis, from which lines are to be drawn to the visual point, A. Each one of the three middle lines determines two points; the two external lines, only one each; these last points being the extremities of a diameter parallel to the basis. The distances of the five points are now to be laid off on the basis, in a direction opposite to the point of distance, and through the points thus determined, lines drawn to the point of distance: these, by their intersections with the visual rays, will determine five points in the curve. The remark made with reference to *fig.* 60, that all natural lines parallel to the basis, are parallel to it and to each other in perspective, enables us to obtain the remaining three points. Through the three points of division to the left of *ab,* parallels to the basis are supposed to be drawn, which must then meet the division points of the circle, opposite to them. Drawing, in the perspective view, lines parallel to the basis, from the three perspective points obtained for those points, these will intersect the visual rays corresponding to the opposite division points. The three deficient points of the curve will then be obtained, with which the perspective view of the circle can be readily completed, as shown in *fig.* 61.

We have hitherto spoken of figures in a plane, that is, of surfaces: to deal with solids, we must determine the height, in addition to the length and breadth. It is to be observed that while the depth of the figure, speaking with reference to the plane of the picture, has its vanishing point in the point of distance, and the breadth in the point of sight, the height must likewise have its vanishing point in the horizontal line. If, then, a certain height be applied to the base, and lines be drawn from its top and bottom to a point in the horizontal line—generally the point of sight—the top and bottom of all bodies which have the height supposed, will lie in these lines.

Fig. 62 exhibits the method of determining the perspective height. Let a four-sided prism be here drawn, whose plane is given, and whose height is yz. A is the point of sight, D the point of distance, and xy the basis of the plane of the picture. After the base, *abcd,* of the object has been perspectively represented at a^3d^3, by the methods already given, apply the height, yz, to the basis, and draw the lines yA and zA; these will contain the top and bottom of the prism for the different planes in the plane of the picture. To ascertain, for instance, the perspective height of the prism at the point d^3, draw a line parallel to the basis, meeting the line yA in 2. A perpendicular line, 2,2′, cutting the line zA, determines at 2′ the perspective shortening of the height yz, for the plane through d^3, and so on for any other point. Let perpendiculars be next erected at the four corners of the perspective ground plane, and parallels be drawn to the basis, intersecting the line Ay, and perpendiculars again from these points intersecting the line Az; finally, draw

from these last points, parallels to the basis: their intersections with the perpendiculars first erected, will determine the four corners of the perspective representation, a^4d^4, of the upper base of the prism.

Pl. 4, *fig.* 63, exhibits the perspective representation of a compound body, viz. a pedestal surmounted by a cross. All the measurements necessary, are obtained from the plan *abcd*, and the geometrical elevation shown on the right hand side. By keeping in view the principles already explained, and observing the correspondence of lettering, the perspective construction will not be difficult. The line of height drawn on the right hand side serves to determine all the heights, as any geometrical height may be marked off upon it, and innumerable lines drawn from the relative top and bottom points: from the different intersections, the shortening in height for any plane in the picture may be determined.

VI. OF THE MOST IMPORTANT MATHEMATICAL AND SURVEYING INSTRUMENTS.

For the better elucidation of the preceding observations, the most important instruments used in geometrical drawing, and the various geodetical operations, have been represented on *pl.* 5, *figs.* 1–56.

The simpler drawing instruments, as the simple compasses, the drawing compasses with movable lead tube and pen point, the drawing pen, the ruler, the scale, and the square, need not be mentioned here, as they occur in every box of mathematical instruments, and consequently are too well known to require description. The first of the rarer instruments to be mentioned, is the *hair compasses* (*figs.* 1, 2), serving for very minute measurements. One foot, *b*, of a common compass, *ab*, is cut off, and a spring prolongation riveted at *d*, so that when it is attached to the head piece, it forms a leg, as in *ab*. The screw *c* can turn at *e* in the rivet, and has its nut in the upper leg. Turning this screw will cause a very slight motion of the spring joint to or from the other leg, independently of any motion in the joint. Very minute differences of measurements or lines may be thus appreciated.

The repeated efforts necessary to divide lines into a certain number of equal parts by the ordinary method, have caused the invention of the proportional compasses. These depend upon the geometrical principle, that in similar isosceles triangles the bases are as the sides. If, then, the legs of two such triangles are to each other as 1 : 2, the bases must be so likewise, and the smaller base will be one half the size of the larger. If we suppose two compasses, so united by their heads as to have a common joint, and the legs in the above mentioned ratio, all the conditions will be fulfilled, and the *bisecting compasses* will be the result. In this, the space between the points of the small legs will be just half of that between the points of the larger ones.

As, however, other divisions besides bisections are required, the head of the compasses has been made movable, thus forming the *proportional*

compasses (*pl.* 5, *figs.* 3, 4). Here the legs *ad* and *bc* are applied to each other, and have two equal slits, in which the plates *f* and *g* pass, convertible by the screw *e* into an ordinary compass joint. This screw forms, then, the point of rotation of the two legs, thus divided into four. Upon the leg is placed a graduation, determining the proportions $\frac{1}{2}$, $\frac{1}{3}$ $\frac{1}{4}$, &c., between the two legs. Loosening the screw *e*, and moving the head until the index mark on *f* coincides with a certain part of the division, $\frac{1}{4}$ for instance, and then tightening the joint, we shall have a relation of $1 : \frac{1}{4}$ between the two sets of legs. The space included between the points of one set of legs, will then be four times that between the points of the other set, whatever be the opening of the compasses. As there is a definite relation between the radius and the side of a regular polygon, another graduation is placed upon the compass to indicate this relation. This graduation is so arranged that when the index, *f*, stands at 1, where all the legs are equal, and consequently $ab = cd$, *ed* will be the side of a hexagon, inscribed in a circle of radius, *ab*. (The side of the inscribed hexagon = radius.) If the index *f* stands at 15, as in *fig.* 3, then $ab =$ radius, and $cd =$ the side of the pentadecagon. *Fig.* 4 exhibits the compasses edgewise, showing the nut of the screw. For the sake of great accuracy, a micrometer screw is sometimes attached to this instrument, as in *fig.* 5. In addition to the arrangements already described, there is a movable nut at *h*, through which passes the slide *k*. To move the head, *e*, by a very slight amount, the slide *k* is attached to the screw *b*, and rendered fast. By loosening or tightening the screw *l*, the slide *k* will be moved backwards or forwards, and with it the head, *e*, to which it is attached. When this is done, *e* is screwed fast, and *k* brought to *i*, where the micrometer arrangement is again brought to play in moving the points *a*, *b*, and consequently, *c*, *d*. We thus obtain *hair proportional compasses*. The lengths *ad* and *bc* must be perfectly equal, or else all indications will be erroneous. The great utility of the proportional compasses consists in their enabling us to enlarge or reduce all parts of a drawing to a certain scale, all that is necessary being to adjust (once for all) the two sets of legs in the same proportion as the required reduction or enlargement.

The common compasses do not answer for long lines. In this case the *beam compasses* are to be used, *pl.* 5, *figs.* 6, 7. These consist of a prismatic beam of wood or hollow prismatic brass rod, *ab*, upon which the boxes, *c*, *d*, slide, capable of being fastened by clamp screws. To each box is attached a point *h*, and *i*, one of them being replaced, when necessary, by a lead tube or pen point. One of the boxes is provided with a micrometer arrangement. For this purpose a head is attached at *f*, through which passes the smooth end of the screw, *e*, without moving back or forwards. The nut of the screw is at *g*; so that when the screw *e* is turned, the spindle being fixed, the nut *g* moves forwards and backwards, and with it the box and point attached.

The *triangular compasses* (*fig.* 8) serve to take off all three corners of a triangle at once, rendering the operation of transferring triangles one of great ease. This instrument has three legs, united in one head in such a manner, that two of the legs form ordinary compasses, in whose head, *a*, a

spindle *f* is inserted by means of the spring, *c*. The end of this spindle is round at one end, where it receives the eye of the third leg, *c*, which may be fastened by means of the plate, *g*, and the head screw, *h*. In this manner the leg *c* may be made to assume any given position with respect to *b* and *d*, and thus any given triangle be taken up with the compasses.

A convenient variety of the triangular compasses is the *plate compasses*, *fig*. 55, which consists of a three-limbed plate, AA, provided with a button, B. At the extremities of the limbs A, A, A are attached the secondary limbs, C, lying in the same plane. Their attached points, *a*, *a*, *a*, may be placed at any required position in the plane of the paper.

It has been seen under the head of perspective and projection, that when a circle is viewed from any direction other than one perpendicular to its centre, it will appear as an ellipse. As such foreshortened circles very frequently occur, and ellipses are troublesome to describe, considerable attention has been directed to the invention of instruments by means of which these curves may be readily drawn. These are called *elliptographs*, of which various forms have been devised. Two of these are represented in *figs*. 9–13. *Fig*. 9 is an upper and *fig*. 10 a perspective view of the oldest and most imperfect of these instruments. This consists of a cross, *abcd*, which has two grooves on its upper surface, crossing each other at right angles. Under these grooves are four points, which when in use are placed in the two axes of the ellipse, so that the middle of the cross stands exactly above the centre of the circle or ellipse to be described. The movable slides *g* and *h* work in the grooves in such a manner that *h* always moves in the groove *ad*, and *g* in the groove *bc*. The slides have boxes above, through which the ruler *ef* is passed, to which the boxes may be fastened by head screws. One end of the ruler *f* carries the drawing point *i*. To use the instrument, place the point *i* upon the extremity of the long axis, and fix *h* at the middle of the cross. Then bring *i* to the extremity of the short axis, and fix *g* at the middle of the cross. If now the ruler be moved, the box *h* will slide in *ad*, and *g* in *bc*, by means of which the drawing point will describe the ellipse represented in the figure.

The defect in this instrument consists in the impossibility of describing ellipses whose axes are shorter than or much different in proportion from those of the cross.

Farey's elliptograph, *pl*. 5, *figs*. 11—13, is perhaps the best yet invented. As far as its size will admit, the entire series of ellipses from a straight line to a circle may be drawn with great accuracy. It consists of two circles, A and B, lying one above the other in such a manner that, by means of the pinion K and the rack-work *d*, any required eccentricity may be given to them. They are fixed at any position by the screws *cc*. The two bridges, *aa*, and the curved arms, *bb*, serve to give the necessary strength to the circles, and to make them sufficiently open to see underneath them. The two circles may be shoved backwards and forwards between the four beams, D, E, F, and Q, which together form a frame-work. These beams lie in two planes, as shown by *fig*. 12, so that F and Q determine the path of the upper, D and E that of the lower circle. In this way the two circles may be moved

so that the centre of each moves parallel to its frame, the paths described being perpendicular to each other, thus constituting the axis of the ellipse. The ellipse itself is described by one point of a small pair of compasses, M, during the working of the two circles, the other point being placed in the foot H. *f* and *f* are buttons by means of which the circles are moved along, while the frame lies upon the paper. The frame is held down with the left hand by means of the buttons N and O. Any required eccentricity can be given to the foot H, as it slides with its frame, *g*, in a groove, and is united to the rack-work, *h*, which is moved by the pinion L. *Fig.* 13 presents a clearer view of the whole arrangement; it is a section perpendicular to the two beams, *a*, *a*, of the circles A and B. *Fig.* 12 is a side view of the instrument.

If both the circles are placed concentric with each other, and the point M placed in the centre, the latter will describe a point when both circles are moved in the frame. If L be turned, M becomes more and more eccentric, and will describe a circle in the movement of the circles, or an ellipse with equal axes. By turning K, both circles become eccentric. If M stand in the centre, it describes a straight line in the movement of the circles; in other terms, an ellipse with one of its axes = O. The different ellipses are obtained by the eccentricity of M. The two buttons, N and O, pass through the ruler, P, which has slits, as well as the prolongations of F and Q, so that the whole instrument can be moved without displacing N and O, which is necessary to the adjustment.

Another instrument for describing various curves, principally epicycloidal, is the eccentric compasses, represented in *pl.* 5, *fig.* 14. This was invented by Suardi, who described 1273 different curves which could be drawn with it. The three legs, A, B, C (the head only of C is visible), form a stand, at whose point of union, C, is placed the principal axis, *a*. Upon this the tube, *b*, provided with a milled head at *r*, may be turned. The strip *d* is fastened to the tube so as to turn with it. The wheels, *e* and *f*, are attached at *d* in such a manner that the axis of *e* may be moved in a slit made in *d*, and that of *f* may be moved on *d* by means of a slide; *g* is a toothed wheel, fixed upon the main axis, *a*. All three wheels may be interchanged or replaced by others, according to the character of the curve. They must all, however, be kept in close contact during their use. The pierced head, *n*, is attached beneath the prolonged axis, *f*, in which may be moved the small strips, *h*, carrying the drawing point, *k*.

The *Pantograph*, in its original form, is an instrument invented by Father Scheiner, intended to reduce or enlarge drawings to any required scale: in other words, to draw similar figures. As the similarity of figures can be attained in various ways, it follows that there must be various forms of pantographs. The two principal systems have been represented in *figs.* 15, 16. Passing by the earlier and more imperfect forms of the pantograph, we represent, in *fig.* 15, the first of these systems. Two rulers, AB and BC, are connected by a joint at B; two others, DF and FE, hinged together at F, are combined with the first two at D and E, so as to form a parallelogram. However much the angular positions of these four rulers may change, they

must always form a parallelogram. Small rollers are placed beneath the four points, D, E, F, and B, to allow the instruments to move freely over the paper. A, G, and C, are three points on the rulers where pipes are attached, and which must always lie in a straight line. C is the fixed point; the tracing point to be moved over the drawing, R, to be copied, is at A, and the drawing point with which the copy, S, is made, is at G. It is evident that in all movements of the instrument, the line CGA will remain straight; the figures described must, therefore, be similar, and the amount of reduction will be greater as G is nearer to A.

The pantograph represented in *fig.* 16, or *eidograph*, as it was called by its inventor, Professor Wallace of Edinburgh, has a very different construction. The bar D moves in the socket A, in which it may be fixed at any point by a screw. To the socket is attached a heavy foot, about which it can rotate. The arms, EH and FG, may also be moved, with reference to the axis of the bar D, the amount of motion being determined by the amount of reduction required in the copy. For this purpose, scales are attached to the bar and arms; a tightly stretched endless string, *aa*, passes round the two pulleys B and C, attached to which are the sockets, in which the two arms, EH and FG, slide, so that these must always make corresponding motions. If the tracing point be at H, and the drawing point at G, and if the three points, H, G, and A, lie in a straight line, then S will be the reduction of R. It is evident that if the tracing and drawing points change places, the copy will be larger than the original, in all pantographs, instead of being smaller.

By a slight change, the pantograph can be so arranged as to copy objects on the same scale as the original; and if the drawing pencil acts at its upper end, and the tracing point at its lower, then the copy will be inverted. This is of great importance to engravers, who are obliged to invert the designs on their plates, so as to have the engravings direct. For this purpose, the plate is placed above the drawing-point, which here consists of a fine etching needle. The pantograph has also been employed for engraving writing.

Two other drawing instruments of great utility are the *spring compasses* (*pl.* 5, *fig.* 17), and the *parallel ruler* (*figs.* 18, 19). The spring compasses, instead of a head, have a strong, curved, steel spring, *b*, to which the feet, *f* and *g*, are soldered. A curved screw, *d*, is fastened in the foot *f*, and passes through *g*. At *e* is the nut of the screw, against which *g* is constantly pressed, by the elasticity of the spring. By the action of this nut the points are separated or approximated. For convenience of handling, a button is attached at *a*. The spring compasses supply the place of the hair compasses, and have the advantage of being firmer, and less liable to derangement when once fixed, for which reason they are employed in describing circles on wood and metal.

The parallel ruler is used to draw parallel lines. Its earliest construction consisted of two parallel rulers, connected by a cross-piece at each end: the more modern instrument, represented from above in *fig.* 18, and laterally in *fig.* 19, consists of a broad ruler, A, upon which the axle B turns, in two small boxes, *aa*. At each end of this axle are attached small and perfectly

equal milled rollers, CC. These rollers pass through apertures made in the ruler, projecting on the other side sufficiently to rest upon the paper. The ruler, carried on this axle with its rollers, will admit of any number of parallel lines being drawn. The greatest possible care must be taken to have all parts of these two rulers perfectly accurate. If the two rulers of the first form be not constantly parallel, or the rollers of the second be not perfectly equal in diameter, the results will be erroneous. The common square, or T square, with movable head, supplies the place of the parallel ruler, and is more certain in practice.

Here also must be introduced the *protractor* (*pl.* 2, *fig.* 74), used in measuring and describing angles. It consists of an arc of brass, generally a semicircle, although sometimes a full circle is employed. In the semicircular protractor, the diameter falls along a ruling edge, and a small notch is made in the middle of this, answering to the centre of the circle. The circumference of the semicircle is divided into 180°, and, if of sufficient size (8—10 inches in diameter), into five minute subdivisions. A rule is sometimes attached to the protractor, turning about its centre, for the purpose of measuring or describing angles more accurately. By attaching a vernier to this rule, very small subdivisions, even to a minute, may be read off.

Directing our attention now to the instruments used in geodetical operations, the first one to be mentioned is the *measuring staff.* This is nothing but a staff of dry, oiled wood, tipped at each end with brass or iron, and divided into feet and inches, for the purpose of measuring straight lines in the field. When in use, it is either laid flat on the ground, or upon posts whose tops lie in a horizontal plane. Two or three of these are always required, in order that when one is laid down, another may be placed in contact with it,—the two extremities touching, and both lying in the same straight line. The first one is then to be taken up and placed at the other extremity of the second, and the operation thus continued. The base line for determining the length of a degree of the meridian in France, was measured by this instrument. Glass rods are sometimes employed, as was the case in the great English trigonometrical survey.

The *measuring chain* (*pl.* 5, *fig.* 27) affords results that are sufficiently accurate for ordinary purposes: it is therefore the one generally employed in common surveying. This consists of links of strong brass or iron wire, connected together by rings, and so arranged that the interval from the centre of one ring to that of the next amounts to just one foot. Ten of such links, or in some cases 12, form one rod, and this amount, and sometimes half and quarter rods, is indicated by rings, D, of peculiar shape. In America *Gunter's Chain* is universally used. Here the entire chain is 66 feet in length (= to four rods or poles), and is divided into 100 links, every tenth link being indicated by a piece of brass of peculiar shape. Each link, then, including the connecting rings, is 7.92 of an inch. At the ringed extremities, A and B, of the chain when in use, chain staves are driven into the ground over which these extremities pass. Each staff (*fig.* 28) has a pointed iron foot, *c*, and a cross piece, *b*, upon which the ring rests, and which is of use to enable the staff to be driven into the ground, by the

application of the operator's foot. In surveying, two chain carriers carry the staves with the chain; the forward one has in addition a number of *arrows* or *pickets* (*fig.* 29). The chain staves are sighted in the line to be measured and driven in, the chain stretched tight between them. The chain is then carried forwards, the forward carrier taking with him the chain staff, inserting an arrow in the hole made by the latter. When the hind carrier comes to the arrow, he takes it up, and inserts his staff, over which the ring of the chain is slipped; the forward carrier then stretches the chain and inserts his staff, which he again replaces by an arrow, and the operation is continued until the line is measured, or the forward carrier has exhausted all his arrows, which are generally ten in number. In this latter case a transfer of the arrows to the forward carrier is made, and the measuring proceeds as before. Careful count must of course be kept of the number of such transfers. This operation is sometimes carried on by means of the arrows and chain alone, the chain staves being omitted.

Of the more complicated surveying or measuring instruments we shall first of all mention the *plane table.* This was invented by Prætorius, hence called mensula prætoriana, and is used to obtain a reduced plan of a tract of land. Of the various improvements made in this instrument since its invention, the two principal are represented in *pl.* 5, *figs.* 20 and 21. *Fig.* 20 exhibits the instrument as modified by Major Lehman of Saxony. It consists of a stand with three feet, *a*, *b*, *c*, shod beneath with iron, and so attached to the stand by joints and winged screws as to allow a horizontal position of the table even on uneven ground. The support, *l*, upon which the board, *m*, rests, may be rotated on its axis; the board itself can be rendered perfectly horizontal by the three adjusting screws, *g*, *h*, and *i*, passing through the plate K. At a later period Lehman did away with these screws, producing the adjustments entirely by the feet of the stand. He also changed the mode in which *l* was turned, by causing it to run out into a disk below, turning on the plate K. This disk had an endless screw turned upon its edge; a spindle attached to *k* caught in this, so as to produce a very slow rotation of the board. The spindle was capable of being removed for coarse adjustments.

Fig. 21 represents a section of the upper part of *Mayer's plane table.* It has also a three-footed stand, upon which the socket, *a*, fits. In the upper part of this socket is an excavation in which the ball or nut, *b*, turns, capable of being fixed by the screw *c*. This nut carries above, the spike upon which the plate AB rests, and to which the metal ring, *lk*, is screwed. *df* is a portion of a middle piece with three curves, through whose extremities, *f*, pass three screws; one of them represented at *h*. These catch in the stirrups, *gi*, *mn*, upon which rests the ring *lk*, with its incumbent plate, AB. By these adjusting screws, the horizontal position of the table is secured. Instead of the female screw at *g*, a knuckle may be attached, as shown at *o*. The screw *e* serves to fix the apparatus to the spindle. This form of the plane table does not give the fine adjustment of the first, as the screws allow a certain amount of spring.

As part of the apparatus of the plane table, we will mention, first, the *fork* (*fig.* 22), which consists of two strips, A and C, fastened by the head, B, in such a manner that they may be slid upon the drawing board. The upper strip, A, runs out to a point which lies exactly above the spot, C, of the lower strip, to which the line for the plummet D is attached. A second plummet is often attached above B. These forks serve to bring a given point on the table directly above a certain point on the ground. The point A is laid upon the point in question, and the table moved until the plummet hangs directly over the spot of earth.

The *erecting compass* is another piece of supplementary apparatus, serving to set up the table in a direction parallel to the original one. This is nothing more than a small magnetic compass with a well divided dial, which can be screwed on the edge of the table.

The *level* serves to render the drawing board perfectly horizontal, this being indispensably necessary to an accurate measurement. It is of two forms—the tub-shaped and the tubular. The *tub-shaped level* consists of a flat cylindrical vessel with an accurately ground bottom, and covered above by a plate of glass. The vessel is filled with alcohol so as to leave only a minute bubble of air, and the top cemented on air-tight. The instrument is inconveniently sensitive when the upper plate is perfectly plane; this is, therefore, generally very slightly convex, so that there may be a tendency in the bubble to seek the centre of the surface.

The *tubular level* (*pl.* 5, *figs.* 23, 24) consists of a frame perfectly plane below, and inclosing a tube of glass closed at both ends. This tube is filled with alcohol, in which is a small bubble of air, which, when the tube is perfectly horizontal, rests in its middle. As the glass tube by itself would be liable to breakage, it is inclosed in a tube of brass, which has a piece cut out of the middle portion above from E to F, to render the bubble visible. This exposed portion of the glass is protected by the bands *aa*. To be certain of the central situation of the bubble, several concentric circles are cut on the cover of the tub level, and on the tube of the tubular level, between which the bubble must rest. Several are necessary, owing to the varying size of the bubble, produced by its expansion or contraction. A small screw is placed beneath the tube level in the socket at B, to correct any deviation from a perfect parallelism of the surfaces.

The *diopter ruler*, or *sight ruler*, is used to determine sight lines upon the plate of the tables. Its simplest construction is exhibited in *fig.* 25. A strong brass ruler, A, with bevelled edges, carries at its extremities two cross pieces, B and C, supporting hinged sight vanes, D and E. The eye diopter, or sight vane, D, contains a narrow vertical slit, or several small holes one above the other. The object vane, E, consists of a frame, in the centre of which a fine hair or wire is stretched vertically. By bringing the slit, the wire, and the axis of the point sighted at, in one line, the projection of the vertical plane determined by this line of sight, may be drawn on the table along the edge of the ruler.

In the preceding construction of the ruler, the sight line itself is not obtained, but one parallel to it. To describe this line itself, the axes of the

vanes must lie in a vertical plane with the edge of the ruler. When this edge is so adjusted, it becomes a *fiducial* edge. For the sake of sighting both forwards and backwards with the same position of the ruler, each vane contains both slit and wire, one above the other; the slit being inferior in the one, and superior in the other. A magnetic needle, F, is sometimes attached to the ruler, in which case the erecting compass can be spared, as it is only necessary to draw a sight line at the commencement of operations, and marking the direction of the needle with reference to this line, to cause the same direction to be maintained at each successive erection of the table.

The form of ruler represented in *pl.* 5, *fig.* 25, naturally serves only for short distances, as far as the unarmed eye can see clearly. To sight at greater distances, the *diopter ruler, with telescope* (*fig.* 26), has been constructed. A plate, C, is fastened to the ruler AB, carrying a telescope of feeble magnifying power. The ocular of the telescope is at E, and in its focus is a vertical cross-hair, which supplies the place of the object diopter. In the better instruments, the tube can be taken out of its bed and reversed: by this means, both forward and backward sighting can be attained. For reduction to the horizon, and sighting objects above or below the horizontal plane, the axis of the telescope can be turned, in a vertical plane, about its axis of rotation. A graduated arc, F, is often attached, which is fastened to the tube, and turns with it, while an index is fixed at G, to the frame. In this manner angles of elevation or depression may be measured. If the index point to the zero of the scale, the tube will be horizontal, and may then be used in levelling.

To illustrate the mode of using the plane table, reference must be again made to *fig.* 57. Taking for instance the figure on *fig.* 57, the first thing to be done is to determine the base *ab*, which it is of great importance to lay out properly. Its chief condition is, that as many points as possible may be determined from it, by intersections which are not too acute. This line must be measured as accurately as possible by the chain and staves. The plane table is then erected horizontally, at A, with the point *a* over the point *a* of the ground, and the north and south line marked. An assistant, with a signal, is then dispatched to *b*. A needle is now stuck in *a*, the point *b* sighted with the diopter ruler, and the line *ab* drawn. With the needle still sticking in *a*, sight lines are drawn to all the principal points visible, as C, D, E, F, G, H, I, K, L, M, N, O, P, Q, R, S, T, which are run out to the edge of the paper, and indicated by letters or numbers, for subsequent identification. In this manner are produced the sight lines *ab, ac, ad, ... as, at.* When the objects have no sharp outline, or are difficult to recognise, as at O and S, signals must be set up, and allowed to stand until the operation is completed. After this has been done, and all the sight lines again gone over, the station A is left, with a signal fixed in it, and the table carried to B, where it is again set up, after having marked on the paper the length of the base *ab*, on a reduced scale, thereby determining the point *b*. This point *b*, on the paper, is brought over the extremity *b* of the base line, first by the eye, and then by the fork,—the table erected horizontally, the ruler laid along the line *ab*, and the table turned until the sight line of the ruler

meets the signal at *a*. After making all necessary adjustments, as examining the compass, observing whether the point *b* of the paper is vertically over *b* of the base, &c., the objects, or signals, C, D, E,——S, sighted from *a*, are again sighted from *b*, and sight lines drawn until they intersect the corresponding lines from *a*. The points of intersection are indicated by the letters or numbers of the sight lines, and well marked, by the pricking of a fine needle, so as to allow the erasure of the lines. The different points thus obtained are finally connected, by straight or curved lines, as the case may require. In accurate measurements, where there is much curvature and few objects, staves, numbered in order, are first of all set up at all the points to be ascertained. In sighting, the signal-carrier, with his flag, goes to each of these stations in succession, and remains until sighted. If the operation is to extend beyond the reach of a single base line, points must be selected from which it may be continued afresh. The position of these new points must be determined from the first base. Further measurements with the chain are not necessary ; if, however, certain important points can be sighted from one spot, and not from another, they may be first sighted and measured, and then transferred to the paper, according to the proper scale of reduction. For a more detailed account of the use of the plane table, we must refer our readers to special treatises on the subject.

The transition from instruments for measuring lines, to those for determining angles, is furnished by the instrument represented in *fig.* 30, *pl.* 5, and invented in 1742. This, in a less perfect form, is mentioned in Speckle's Festungsbau, 1608. Zollman has improved it so much, however, that it now bears his name. It is represented in our figure as improved by Gerstenberg, of Jena. It consists of a tripod stand, upon which is fastened the board A, as in the plane table. The erecting compass C serves to set up the instrument properly. There is a pivot at the centre B, upon which the diopter ruler, the alidade D, with the two sight vanes, E and F, can turn. The board is covered with the drawing paper, and upon it is placed the frame seen on the exterior of the board. This frame is graduated to degrees of the circle, and marked accordingly. The instrument is now set up at a station, at which a certain number of angles is to be ascertained, and the legs of these angles determined by sighting through the diopters, afterwards to be measured by a protractor, or by the graduation in the frame. The advantage of this instrument consists in its giving the angles themselves, and not, as in other angular instruments, their numerical values.

Of the purely angular measuring instruments, the first to be mentioned is the *astrolabe*. It is exhibited in *fig.* 31 on its tripod stand. By this is not to be understood the astrolabe of Hipparchus, used in determining the altitudes of the stars, but the common astrolabe, used by surveyors for hundreds of years, and which even now maintains its place, when well constructed, as an excellent means of measuring angles. It consists, in the semi-astrolabes, of a large semicircle, D, divided to 180°, and in the full astrolabes, of a large circle divided to 360°, and generally graduated also to quarter degrees. A strip, A, is attached in the direction of the diameter, which passes through 0° and 180° ; this strip has a tongue at H to enable it to be

placed perfectly centrally upon the stand. This strip carries two fixed diopters, or sight vanes, B and C, as well as the centre. Another strip, E, turns about the centre, one end of which in the half-astrolabe (both ends in the full astrolabe) traverses the graduated limb and carries the sight vanes G and F. The middle line of this alidade coincides with the axis of the sight vanes and the centre, and is marked upon the bevelled edge of the alidade as an index. The diopters are both ocular and objective, for fore and back sighting. The limb of semi-astrolabes is doubly marked, first from 0° to 180°, and then from 180° to 360°, the 180° of the second corresponding to the 0° of the first. A small compass is often attached at the centre, and the tongue H fitted up with nut and screw as in *fig.* 21, so as to permit the circle to be brought from the horizontal to the vertical position, thus allowing a measurement of altitudes. To measure an angle with the astrolabe, it is placed with its centre over the vertex of the angle, and turned until the fixed diopters sight in the direction of one leg. The movable strip with its diopters is then to be sighted in the direction of the other leg, and the angle contained between the two strips, read off. To measure several angles from the same station, the first diopter may be left fixed, and the alidade moved successively to the different angles. Thus if the first angle measured between the fixed strip and the alidade amount to $35\frac{1}{4}°$, and the second to $97\frac{1}{2}°$, the angle contained between the two positions of the alidade will be $97\frac{1}{2}° - 35\frac{1}{4}° = 62\frac{1}{4}°$. The astrolabe may, with a little practice, be made to perform much of the work of the plane table. Telescopes are sometimes attached, instead of the alidades. The instrument in this case falls rather in the class of the theodolite and graphometer, to which we shall shortly refer.

The *compass*, represented from above (*fig.* 33, *pl.* 5), and from the side, in *fig.* 34, is another instrument for measuring angles. It depends upon that property of the magnetic needle by which its direction is always parallel to that of the magnetic meridian, called north and south line. Even if the magnetic meridian of several places be not parallel, strictly speaking, yet the difference within a degree of longitude is so slight, as to be zero for all ordinary purposes. The compass consists of a round or square box, AB, in whose centre is a pivot, C, upon which a magnetic needle, DE, plays freely. The relative position of the latter may be read off on the limb, graduated to half and quarter degrees. To prevent the needle from playing when not in use, whereby both it and the pivot would be injured, a stop, or arrester, F, is attached: by this the needle can be lifted from the pivot, and pressed firmly against the glass covering of the box. The plate of the compass is dressed truly square, with two edges parallel to the north and south line, and three of the edges bevelled. In this way the compass itself may be used for laying off angles, by which means numerous errors may be avoided. In using the compass, it is attached to a tripod stand, by the socket I. This socket has a contrivance at G, with nut and screw for fixing, and a rim, *abcd*, is screwed upon the plate AB, which serves to carry the telescope IH. This is made fast by the screws *ef*, but may be turned, in a vertical plane, about the point G. The connexion with the socket, I, takes

place by means of a plate, with screws. To use the instrument, it is placed upon the stand, which is set over the vertex of the angle to be measured, and turned, until the sight line of the telescope falls in a vertical plane with one leg of the angle to be measured. The position of the needle is then to be noted. Suppose A to be $36\frac{1}{4}°$: the compass is again turned, until the axis of the telescope lies in the vertical plane of the second leg. As the needle, DE, retains its parallel position, it will now intersect a second point on the limb, which must also be read off. Suppose this to be $120\frac{3}{4}°$: then the angle measured will be $120\frac{3}{4}° - 36\frac{1}{4}° = 84\frac{1}{2}°$. Any number of angles may be thus measured from a single station, and their legs measured with the chain.

Although the compass has received various constructions, and is in general use, it is considerably behind the plane table in the accuracy of its results. The latter gives its results directly, instead of comparing them by the comparison of several measurements. In the compass, errors may occur in reading off the angles, which can never be determined to a greater degree of accuracy than $\frac{1}{10}°$; this defect, added to several others, may introduce false results of no inconsiderable magnitude. As an illustration of this contingency, let us refer to *pl.* 4, *fig.* 11, where, by a slight error in determining a single angle, the defective figure A′B′C′D′E is obtained instead of the correct one ABCDE.

The *prismatic compass* of Schmalkalder (*pl.* 5, *figs.* 35, 36), improved by Major von Decker in 1810, is well calculated for rapid military surveying. It consists of a plate, upon which is a small compass of about three inches in diameter, upon whose needle, *o*, a disk of pasteboard with a graduated limb is so fastened as to turn with it. The arrester or stop, *b*, serves to lift this slightly from its pivot, when not in use. The sight vanes are attached in the direction of the diameter; the objective at *h*, and the ocular at *f*, with their axes in the same vertical plane. A three-sided prism, *ade*, is attached to the ocular diopter, having a small mirror in its hypothenuse, which looks towards the graduation of the limb. To use this instrument, it is to be held horizontally before the eye in the vertex of the angle to be measured, and a sight taken through the upper part of the two vanes along one leg of the angle. Then, by the turning of the needle, a number on the limb will come under the prism, which, reflected by the mirror, can be read off through the lower part of the slit *g*. The second leg is then to be sighted in the same way, and the angle itself determined as in all compasses. The arc *m* serves for the rectification of the instrument, with reference to the variations of the needle. The graduation on the limb is inverted, so as to be seen directly by reflection from the mirror. The diopters can be made to turn down when the instrument is to be packed up, in which case the stop *b* is to be set, the point *n* for regulating *m*, fixed, and then the whole may be packed in a box four inches square, and one and a half inches deep. Its indications are sufficiently accurate for such purposes as military reconnoissance, &c.

The theodolite, as represented in *fig.* 38, *pl.* 5, is a perfected form of the full circle astrolabe. This instrument is calculated, not only for operations

of the lower geodesy, but for trigonometrical surveys, and even for the most delicate astronomical measurements. It rests upon a tripod, K, with which it is fixed on a special stand, or upon the plate of a plane table. At the end of the feet are the setting screws, *a*, *b*, and *e*, by means of which a perfectly horizontal position of the instrument can be attained. At the junction of the three feet there is erected a shaft, which carries the entire upper portion. Over this is slipped a socket, with a foot plate, L, which can be turned about the shaft by the action of a male screw, *c*, upon an endless female screw cut in its periphery; the plate may be fixed by the clamp *d*. This socket carries a correcting telescope, IH, which may be turned about the vertical shaft, independently of any motion of the foot or of the upper portion of the instrument. Over this socket rests a pierced circular plate, A, which can be fixed to the shaft, and upon which turns a circle provided with a limb, and capable of being fixed by a clamp screw, G. On the inner edge of this circle rests the accurately fitting alidade ruler, B, which, in some instruments, may form a full circle. This ruler, or alidade circle, carries an index provided with a vernier, as also the tube level C, by means of which the horizontal position of the instrument, and in particular of the circle A, may be insured. The bearer, F, of the telescope, DE, stands vertically over the centre of the alidade, the telescope supplying the place of the sight vanes, and being capable of motion in a vertical plane. A graduated arc, with index and vernier, is attached, for the purpose of measuring angles of elevation and depression. In using the theodolite, it is placed upon the stand, or the plane table, and fixed in a perfectly horizontal position by means of the setting screws, *a*, *b*, *e*, and the level C. The lower telescope is now to be directed to some fixed object, or, if none such present itself, to a temporarily fixed movable one, as a signal flag, whose centre is intersected by the vertical cross hair. This adjustment is made by means of the spindle *c* acting on the female screw in L; when completed, the clamp is to be applied, and the telescope fixed. It must now remain in this position throughout the operation, to insure the immobility of the whole apparatus. The clamp screw G is then loosened, by which means the circle A is set free: this, with the alidade, is to be turned until the cross hair in the telescope DE meets one of the two objects whose angular distance is to be measured, consequently lying in a vertical plane with one leg of the angle. The limb is now to be fixed by the clamp screw G, and the alidade B turned until the cross hair in the telescope DE meets the second of the objects, the telescope thus lying in a vertical plane with the second leg of the angle. The interval traversed by the index, in shifting from one leg to another, will represent the angular separation of the objects, and will give the angle required. If the objects lie in different horizontal planes, the telescope must be elevated or depressed to meet this case. The vertical limb will give the angular value of this elevation or depression.

When observations are conducted in a certain manner with this instrument, it becomes a *repeating or compensating circle.* In reading off the angles, slight errors may creep in, even with the greatest care taken to avoid them: to compensate for these, the operation must be repeated. For

this purpose, when the angle has been measured, other things remaining the same, the clamp G is loosened, and the alidade telescope is brought again to the first object, without displacing the index: the clamp is to be applied, and the measurement gone over again. This operation may be repeated several times. The mean of these several measurements is then to be taken, which will in general be more accurate than any single one. In the common alidade there are two indices with verniers, and in the circular alidade four, at right angles to each other, so that at each single measurement, the mean from two or four observations can be taken.

The *Graphometer* (*pl.* 5, *fig.* 37) is essentially only a simplified theodolite, applicable to the minor geodetical operations. It is fixed on a stand by means of a socket and screw, K, and has the nut and screw arrangement, I, together with the correcting telescope, GH. Instead of the full circle, there is only a semicircle, A, upon which, besides the level, C, is attached an erecting compass, *a*. The clamp *b* serves to fix the instrument, as in the theodolite, and the alidade B has only one index with vernier. The upright, D, carries the telescope, EF, which has no graduated limb attached. It is used like the theodolite, although repetition is only practicable in the case of very acute angles.

Reflecting instruments, as a means of measuring angles, are next to be mentioned. In these, only one leg of the angle to be measured is observed directly, the signal of the other being attained by reflection into the field of view of the instrument. Reflecting instruments were first invented by Hadley, in 1740, for use at sea, where a fixed stand, or several telescopes, could not be employed; thence they were transferred to astronomical and geodetical operations.

Hadley's sextant (*fig.* 32) consists of a sector, containing the sixth part of the circle, or 60°. This arc, AB, forms the base of the instrument, and to it are attached two radii, and several cross pieces for the sake of additional strength and stability. Upon one of these radii is a post with a ring for attaching a small telescope, in the prolongation of whose axis on the other radius is attached the objective, H. The objective is divided into two equal parts, of which the lower, H, is a mirror, and the upper, G, a transparent plate of glass. A vertically central line passes through both halves. The central piece, C, consists of two superincumbent plates, turning on a common axis, and in the prolongation of this axis a plane mirror stands perpendicularly, so that when the index D, which moves over the limb on an arm in the prolongation of the mirror, stands at 0° of the scale, the two mirrors are parallel to each other. E is a small frame with colored glasses, which can be turned up to protect the eye during sunshine, or in observations in the sun. To use the sextant, the observer stations himself in the vertex of the angle to be measured, and directs the instrument in such a manner that one of the objects is seen through the telescope and the upper part of the objective. The arm with the index is then turned until the second object is reflected from the mirror C to the mirror in the lower part of the objective, and the fine adjustment made by means of the tangent screw, *b*. This adjustment consists in causing both objects to be

bisected by the vertical line passing through the objective. According to optical principles, the angle thus obtained and read off on the limb, is just half of the actual angle of separation, so that the limb, instead of a graduation of 60°, is actually divided into 120 divisions, each one of which represents a degree.

Mayer of Göttingen, and after him, Borda, have improved the sextant by employing a full circle instead of the sextant. This forms the *reflecting circle* of Borda, and is represented on *pl.* 5, *fig.* 39. Here B is the graduated circle, placed upon the stand, A, similar to that of the theodolite, and capable of receiving a correcting telescope. K is a movable alidade, frequently a full circle, as in the theodolite, and provided with a vernier, N, and a correcting and clamping arrangement, I. On the alidade is a telescope carrier, FH, with a vertically movable telescope, G, and the objective, M, constructed as in the sextant. The dark glasses already mentioned are at O. The central-piece, C, is constructed as in the sextant, and carries the mirror, L, with the index, C, which has also a vernier, and a correcting and a clamp arrangement, D. E is a lens for reading off the graduation. P and Q are verniers for repeating. This reflecting circle, besides admitting the measurement of larger arcs than the sextant, has the advantage of being a repeating instrument.

To make use of the reflecting circle, the alidade, K, is so adjusted that one of the two objects is visible through the upper part of the objective, and the alidade, C, moved until the mirror, L, reflects the second object into the lower half of M. The angle at C is read off, and doubled for the true result. The principle of repetition is here the same as in the case of the theodolite.

It becomes necessary to add a word or two in explanation of the vernier (*pl.* 5, *figs.* 49, 50). The vernier, so called from its inventor, Peter Vernier (1600), is an arrangement for reading off small quantities on a scale, with great accuracy. Owing to the small size of mathematical instruments, the graduations upon them cannot be very minute, and it is rarely that quantities so small as $\frac{1}{4}$ of a line, or $\frac{1}{6}$ of a degree, can be indicated. A minuter division, so necessary, is attained by the use of the vernier. If a certain length, *am* or *an*, be supposed to be divided first into 10 and then into 9 equal parts, one part of the first division will be $\frac{9}{10}$ of a part of the second. If both divisions are placed one over the other, then, calling the first *a*, and the second *b*, the first part of *b* will project $\frac{1}{10}$ of its length beyond the first part of *a*, the second part $\frac{2}{10}$, &c., until the ninth and tenth will again coincide. Other numbers besides 9 and 10 may be employed, or an arc may be divided instead of the straight line. Suppose the limb of an instrument to be divided into quarter degrees, then each such part = 15 minutes; take 14 of these parts and divide them into 15, then each new division will be $\frac{14}{15}$ of the old, and each old one $\frac{1}{15}$, or one minute, greater than the new. By taking the axis of the alidade as the centre or zero point, and describing the given graduation to the right and left of this centre, the vernier will be capable of indicating single minutes. Suppose that in measuring an angle, the zero of the vernier has been found to be between $36\frac{1}{2}°$

and $36\frac{3}{4}°$, or that the angle is greater than the former and less than the latter. To determine the differences, find what division of the vernier accurately coincides with a division of the limb; let this be the tenth on the right side. We know that each part of the limb is one minute greater than any part of the vernier, consequently, for 10 divisions of the limb, we must add 10 minutes; then, $36° 30' + 10 = 36° 40'$. If the divisions thus met, had been to the left of the centre, the number of minutes thus ascertained would have to be subtracted instead of added. The same reasoning applies in the case of the rectilineal vernier.

It still remains to mention *levelling instruments*, used to determine the direction of a horizontal plane. Of these, the simplest is the common *mason's level* (*pl.* 5, *fig.* 56). It is known that every line hanging plumb must be perpendicular to a horizontal plane, and that a line from the vertex of an isosceles triangle to the middle of the base, will be perpendicular to the base. Upon these principles rests the determination of a horizontal position by the *foot level.* This is an isosceles triangle, *abc*, from whose vertex depends a plumb line, *cf.* If this be placed upon a board, and one end elevated or depressed until the plummet hangs opposite to the middle of the arc, *de*, the base of the triangle will be horizontal. This instrument can only be used for short distances—12 feet at the most—and for greater lengths, other means must be employed. The first to be mentioned is the *water level* (*fig.* 40). This consists of a simple stand, A, upon which, by means of a socket, B, is placed a tin tube, CD, bent at right angles at both ends. In each end, two glass tubes, E and F, are cemented water tight. If this water level be filled with water until it enters and partially fills the glass tubes, the upper surface of the water in both of these will stand in the same horizontal plane, independently of the position of CD. The horizontal plane thus indicated may be prolonged at pleasure, by sighting forwards at a given signal. An adjustable objective, IK, placed exactly over the middle of the instrument, is sometimes employed to furnish to the eye a more convenient point of reference, and to enable it to do with but one surface. The *movable diopter* (*fig.* 41) is, however, better calculated for this purpose. B is the bent part of the level, E the glass cylinder, cemented in the collar, *a;* the support, *b*, is attached to this collar, and in it a rack, *cd*, may be moved up and down by means of the pinion, *k*. The diopter is seen at *f;* its aperture, *g*, is divided into two parts by the horizontal thread, *hi*. At the commencement of the operation, the two diopters are brought to an equal height with the surface of the water, in which case sights may be taken over the threads, instead of over the surface of the water. In some cases the tubes inclose floats, supporting diopters, with a horizontal cross hair in each; these hairs must both be at precisely the same height above the water.

The *mercurial level* of Keith (*figs.* 42–44) is much more complete than the water level. This consists of a wooden box, AB, in which is a canal, EF, filled with mercury to a certain height, and then covered tight. At the two ends of the canal are rectangular boxes, C and D, into which mercury flows from the canal. GH is a bottom, separating the upper part, IK, of

the box from the canal. OK is an entirely inclosed space, cut off by the partition P. The cubes, S and T, fill the boxes C and D, so as to move freely up and down in them without shaking. These cubes carry above the diopters U and V, shown in *fig.* 44, having an aperture divided by a cross hair, X. *Figure* 43 is an under view of the instrument. The left hand side of *fig.* 42 exhibits it in section, and the right hand side in a lateral view. The entire instrument is connected by means of the strip *ab* (*fig.* 44), and the screw *c*, with the socket *d*, with which it is placed upon a stand: it can be fastened by the screw *e* (*fig* 42). To use the instrument, the canal EF is filled with mercury, whose surface naturally assumes a horizontal position. The two equally heavy, and in all respects similar cubes, S and T, are placed upon the mercury, which has flowed into the boxes C and D, and the cross hairs of the diopters will be in a horizontal plane, which can be produced by the sighting of signals. When not in use, the bottom G is pushed from under the bottom H, and the instrument is so constructed, that the mercury enters into the spaces M and N, which then are closed by sliding back the bottom G. The whole may then be transported without shaking the mercury. On account of the influence of the mercury upon brass and copper, these metals must be avoided. The cubes, with the diopters, should be constructed principally of ivory.

All these forms of levels being constructed with diopters or sight vanes, are applicable only to short distances; for long distances telescopes must be employed. The tube level is employed in this case for securing a horizontal position of the axis of the telescope. The tube level is preferable to the tub level, on account of its greater length and sensibility, and to the mercurial and water levels, for its greater convenience in use, as also for its superior delicacy.

Fig. 46 represents the simplest form of levelling telescope. This is placed on the plate of the plane table, by means of the tripod A, and the level rendered horizontal by means of the setting screws, *a*, *a*, *a*. The foot A is hollow, and in it turns a pin with a plate, B, upon which rests CD, the carrier of the level and telescope. The level, EF, rests in a peculiar frame upon this carrier, one end on a spring which is compressed by the pressure screw G. This spring serves to correct the level in case its axis should not be parallel to that of the telescope. In the supports erected at C and D, the telescope KL rests; it is held there by the clip springs H and I, which can easily be thrown back, to allow the telescope to be taken out and reversed. In the focus of the ocular there is a cross hair of human hair or spider's web, which is so fastened in a frame as to be capable of being placed exactly in the axis of the telescope, by means of the screws *b*, *b*. In this instrument the axis of the telescope answers to the sight line of the diopters in the water level. When it is once set up horizontally, levels may be taken in every direction, by turning the level and telescope bearer on the foot A.

The *level and compass* (*pl.* 5, *fig.* 45) is a more complicated instrument, possessing the advantage of being able to measure the angle formed by one leg levelled with another. This level has its own stand, with three feet, P,

Q, and R, upon which the plate L′ rests. This is so connected with the plate L, as that the setting screws, *e*, *e*, *e*, can render the latter horizontal, and with it the whole apparatus. The screw, N, serves in addition to turn the instrument horizontally about its axis, and the screw, M, is a clamp to hold it in any position desired. The compass, I, lies in the middle of the arm FG, and at one end is the support E for the telescope; the other support, D, stands upon a screw, by means of which it can be placed somewhat higher or lower in the arm FG, for the sake of ascertaining certain necessary corrections in the parallelism of the whole instrument. The supports are called Y's, from their shape, which affords a steadier position to the telescope than if they were semi-cylindrical. The collar bands, *f*, are attached to the Y's by hinges. The level *cd* is suspended from the telescope AB, by special collars, and is firmly fixed to A; by this the parallelism is more perfectly secured. This telescope has a cross hair which can be brought out of the axis by the screws, *b*, *b*; *a* is the handle for managing the telescope when it becomes necessary to reverse its position.

The *levelling compass* (*pl.* 5, *fig.* 47) has for its object, in addition to the purposes of the preceding instruments, that of measuring altitudes. It is fixed on a tripod stand by the socket A and screw *a*, and has an arrangement, by means of the screws, *b*, *c*, for producing a horizontal position and a rotation. It consists of a compass, I, to whose border the level D is attached. By means of the clamps *d* and *b*, the circular limb E is attached near the level, and perpendicular to the plane of the compass. About its axis the telescope C, fixed to the alidade GH, rotates vertically up and down. The alidade has a vernier at G, which can be fixed at the zero of the scale on the limb E, by the clamps at F and H. This will be the case when the axes of the telescope and level are parallel. To measure altitudes, the clamp screw, H, must be loosened, and the tube directed towards the object while the instrument still remains horizontal.

The *levelling circle* (*fig.* 48), which is actually only a modification of the repeating circle, may be used as a universal measuring instrument. It has a foot, A, with the screws, *a*, *a*, *a*, for horizontal adjustment. The correcting telescope, CD, is attached to the socket B, and is capable of being fixed by the screw contrivance, *c*, *b*. The telescope carrier, H, with the vernier alidade, G, moves on the limb EF, being managed by the screw *c*. The telescope IK rests upon the support H, and can be fixed by means of a special arrangement, at any position in a vertical plane. The level, L, rests upon a plate, M, with two small processes, which pass between the beds *e* and *f* of the telescope.

In addition to the levelling apparatus already mentioned, there still remain the *levelling staves* (*figs.* 51, 52), and the *sight vanes*, or *targets* (*figs.* 53, 54). The staves are divided into feet, inches, &c., and the height is read off from the ground to the point where the sight line of the diopters or telescope intersects the staff. *Pl.* 5, *fig.* 51, exhibits one of these staves divided on the right hand side into feet and inches, and on the left into decimetres. A vane or target moves up and down the staff, until the central horizontal line of the vane falls in the horizontal plane of the level, the corresponding

point in the scale is then to be read off. This upward and downward motion takes place, as shown in *fig.* 52, by means of ropes and pulleys. Pulleys, *a* and *b*, are attached at the top and bottom of the beam AB, over which the endless string *cd* passes. E, the carrier of the vane or target, is fastened to the string at F, with which it must move. The sight vane may have very different constructions; the great object of all, however, is to show the horizontal line with the greatest possible distinctness at considerable distances. Thus in *fig.* 51 there is a broad black stripe at AB, through whose centre runs a white horizontal line. The vane has an opening through which the point of elevation of the central horizontal line can be ascertained. Other vanes are four cornered or circular, and divided into quadrants which are alternately red and white, or black and white; others are arranged as in *fig.* 53, where AB, the central line, is drawn black on a white ground. Here *abcd* is the arrangement for fastening the target to the staff. The same is seen at NOPQ (*fig.* 54), on the hind side of the target. The target is screwed to the sliding piece. In levelling with targets of the construction just described, the central line is marked on the hind side, and the graduation of the staff is also posterior. The perforated vanes (*fig.* 51) are better, however, as the leveller can frequently read off through his telescope, and thereby control the operations of the vanesman.

ASTRONOMY.

PLATES 6–15.

ASTRONOMY is that science which teaches the distribution and arrangement of the various heavenly bodies, their true and apparent motions in space, their magnitudes and distances, their physical structure, so far as known, and their mutual influences, so far as these influences are indicated by observations and established by induction.

The high importance of this science is evident to every reflecting mind. Its elevated object needs only to be mentioned to awaken feelings of dignity and grandeur in the human breast; for the conceptions and ideas it arouses of the infinity of the universe, and of the power, wisdom, and goodness of the Creator, excite in otherwise insensible dispositions, feelings of astonishment, admiration, and reverence. The benefits which human society (man) has derived from Astronomy, particularly with regard to the more accurate determination and division of time, the perfection of distant navigation, the fixing of the geography of places, &c., have been of infinite importance. To every cultivated mind, the exact knowledge of the true connexion and relation of our planet to the universe, if not absolutely indispensable, is yet most useful and attractive: it elevates the reflecting mind above an undue estimate of the size and importance of the earth, by showing its insignificance in respect to the great whole; it enlarges the circle of ideas, calls to mind the infinite, the unchangeable, and awakens longings and hopes in the soul, whose realization and continuation beyond the stars may form one portion of future blessedness.

Astronomy is divided first of all into three parts. 1. *Spherical Astronomy*, which teaches the knowledge of the various points and circles of the celestial sphere, the constellations, the position of the stars with respect to these points and circles, as also the phenomena occurring in the sphere of the Heavens. 2. *Theoretical Astronomy*, which enables us to determine from observation the true paths of the heavenly bodies, particularly of the planets. 3. *Physical Astronomy*, which gives the laws by which the motions of the heavenly bodies are regulated, shows how these motions are to be calculated according to the rules of mechanics, and finally combines all that is known up to the present time, of the physical characters of the heavenly bodies.

Practical astronomy is to be considered as the basis of these three divisions, which together form *theoretical* astronomy. This may be divided into: 1. *Observing Astronomy*, which treats of the apparatus (instruments),

and the observations made with it: 2. *Calculating Astronomy,* which teaches the method of obtaining from the observations the calculated results. For a well-grounded study of astronomy, a knowledge of pure mathematics, of mathematical physics, and of the sciences of optics and mechanics, is necessary. To become a practical astronomer, talent for observing, and a readiness in calculating, are required.

Astronomy, from its very nature, gives quite an abundant opportunity for pictorial representations, which have for their object either to explain theoretical propositions, or to make a visible exhibition of the objects and phenomena of the starry heavens. It might, however, be a not uninteresting preliminary, to take a historical survey of this science, showing how the investigating disposition of man has been occupied in its endeavor to obtain a more accurate and perfect knowledge of the Universe.

It is highly probable that the earliest nations, incited by the beauty of the starry heavens, and the necessities of life, gradually learned the changes of the days and seasons, the course of the sun, the moon, and some planets. The Chaldæans introduced the twelve signs of the zodiac, the sun-dial, and the clepsydra or water clock; and also laid the foundations of Astrology. The Persians and Babylonians determined the sun's year at $365\frac{1}{4}$ days; the Phœnicians applied Astronomy to navigation; and that the Egyptians possessed astronomical knowledge is abundantly shown by characters on their obelisks and temples. The Chinese seem to have known and used the gnomon from the most remote antiquity, and the Emperor Yao (2367 B. C.) determined the moon's year to be 354 days. At the time of Hoang Ti, they were acquainted with the equinoctial and solsticial points. The Greeks, however, first raised Astronomy to a higher level: Thales (640 B. C.) knew the cause of eclipses of the sun and moon; Anaximander constructed a geography and the first map; and Meton introduced the moon's cycle of nineteen years, to reconcile the moon's year with the course of the sun. Aristarchus (born 267 B. C.) was the most celebrated astronomer among the Greeks; he even guessed at the motion of the earth around the sun. He was followed by Hipparchus, who, by means of the equinoxes, determined the sun's year to be 365 days, 5 hours, 55 minutes, 12 seconds; and also constructed a catalogue of fixed stars. Ptolemy likewise sketched out a catalogue of fixed stars, as also a system of the universe, called after him the Ptolemaic system. The Romans had too little taste for mathematics to become good astronomers: Seneca alone, with a few other Roman philosophers, had just ideas of the heavenly bodies; the Romans were, however, so much the more given to Astrology. Julius Cæsar introduced the calendar invented by the Greek, Sosigenes, and called, after him, the Julian. Later than this, when learning fled to the newly established cloister, Astronomy was cultivated almost exclusively by the Arabians, particularly from A. D. 650. Albatari prepared astronomical tables; and in the time of Almansor, the moon's year was introduced, which is still in use among the Turks; but after the death of Almansor (in the 10th century), the study of Astronomy among the Arabians died away, and during the middle ages scarcely anything was esteemed but Astrology. Charlemagne, Gerbert

(Pope Sylvester II.), the Emperor Frederic II., King Alphonso of Castile, and some others, make the only honorable exceptions by their active participation in the study. Alphonso the Tenth held at Toledo, in 1240, an astronomical convention, whose fruit was the Alphonsine tables. At a later period appeared the first European astronomers, properly so called, Vitello, Bonatus, Purbach, John of Gamundia (first rectifier of the calendar), and Regiomontanus (calculator of ephemerides). At the end of the fifteenth century, Savonarola and Picus of Mirandola earnestly contended against Astrology. All were, however, eclipsed by Copernicus, who, in 1508, presented to the world his theory, and its proofs, of the true arrangement of the planets in our system. Nevertheless he found many opponents, particularly Tycho Brahe, one of the greatest of practical astronomers. This latter individual defended the immobility of the earth, and presented another system of the planets, known under his name, which was, however, very soon overthrown by the celebrated laws of Kepler (1571–1630), who constructed the first tables (the Rudolphian), calculated according to the Copernican system. A contemporary of Kepler, Galileo, was in a measure the martyr of the Copernican theory, for he was obliged to renounce at Rome his belief in the double motion of the earth; this, however, could not hinder the spread of truth, since at this time the telescope was invented, by means of which an entirely new view of the universe was gained. The mountains of the moon were discovered, the phases of Venus, the moons of Jupiter, the spots of the sun, &c., all of which testified to the truth of the Copernican theory. Huyghens, the inventor of the pendulum, discovered a moon, and the true shape of the ring of Saturn. In the seventeenth century, Halley, Flamsteed, Hevel, and others, examined the heavens incessantly and accurately, and Newton was the immortal creator of Physical Astronomy, by his discovery of the law of gravitation. The delusion of Astrology now vanished, and there remained alone the fear of great comets. In the eighteenth century, Euler, Clairaut, and D'Alembert, worked out still further Newton's Mechanics of the Heavens. Dollond invented the achromatic telescope, and, somewhat later, Herschel brought the Newtonian reflecting telescope to a wonderful degree of perfection: the discovery of the planet Uranus and his six moons was the result. A little before this, Mayer constructed his accurate tables of the moon. Bradley discovered aberration and mutation, and Lacaille, at the Cape of Good Hope, mapped out the southern hemisphere. Maupertuis, in Lapland, and La Condamine, in Peru, carried on measurements of a degree, in order to a more accurate determination of the size and figure of the earth; this end was, however, first obtained during the end of the last and the beginning of the present century, by the well known great French measurement of a degree. After Laplace and Lagrange had worked out in a masterly manner the theory of planetary perturbations, Bürg, Burckhardt, Zach, Carlini, Lindenau, Bouvard, Damoiseau, and others, were enabled to construct their sun, moon, and planetary tables, which agree within a few seconds with the actual positions of those bodies. At the commencement of the present century, not a few comets were discovered by Olbers, Pons, Mechain, Huth, and others, as also the

planets Ceres, Pallas, Juno, and Vesta, by Piazzi, Olbers, and Harding. Lalande, Bode, but especially Maskelyne and Piazzi, prepared fuller and more accurate catalogues of the fixed stars. Gauss taught new and very ingenious methods of accurately computing the planetary orbits, while Bessel attained the reputation of one of the greatest theoretical and practical astronomers that ever lived. During this time, however, the art of constructing astronomical instruments and achromatic telescopes was not behindhand, as the names of a Dollond, Ramsden, Troughton, Reichenbach, Fraunhofer, Repsold, and others, can satisfactorily testify. Finally, in later times, the appropriate and well arranged observatories at Altona, Berlin, Göttingen, Greenwich, Helsingfors, Königsberg, Ofen, Paris, Pulkowa, Seeberg, Vienna, &c., have been erected, and three new planets discovered —Astrea, Neptune, and Iris—and the existence of a central sun has been indicated by Mädler. Our century can point to a mass of accurate observations which have already been employed by theoretical astronomy to such account, that the science of the stars has been raised to a giant height, almost to entire perfection—a perfection which hardly any other branch of human knowledge can boast.

I. SPHERICAL ASTRONOMY.

The Armillary Sphere; the most important Points, Circles, and Terms in the Celestial Sphere.

THE ARMILLARY SPHERE.

1. The ancients at an early period imagined the existence of certain points, circles, &c., on the sphere of the heavens, by means of which they might the more readily comprehend, and be the better able to follow the various celestial phenomena. They also invented an instrument, the *armillary sphere*, partly with the view of giving an intelligible exhibition of the mutual relation of these points and circles, and of the axis of the heavenly motions, and partly to make actual observations by means of this sphere. The *armillary sphere* (*pl.* 6, *fig.* 1) consists of a frame, with a horizon on which are represented the 360 degrees, the regions of the heavens, the calendar, and the height of the sun for every day in the year. Two notches in the horizontal circle, and corresponding to its north and south points, receive the *fixed meridian*, whose plane is perpendicular to, and centre coincident with that of the horizontal circle. This meridian, within which the other circles as well as the small terrestrial globe may all be rotated together on the common axis of the heavens and earth, can be moved in these notches, still remaining in the original vertical plane; in this manner the general axis may be placed at various angular distances with the horizon. The centre of the small terrestrial globe is coincident with that of the general armillary sphere, the names and position of the

other circles are evident from the figure without further explanation. The hour circle fastened to the north pole of the fixed meridian has a movable index, which, when fastened, revolves with the axis. The artificial sphere known as the celestial globe has the advantage over the armillary sphere in allowing the representation of the stars; but the latter exhibits to the senses far more clearly the relation of the most important points and circles of the celestial sphere to the inclosed terrestrial globe.

2. *Fig.* 2 gives likewise an explanatory representation of the most important points of spherical astronomy. The circle EHZT is the *fixed meridian* or *noon circle;* if its surface represent the western hemisphere of the celestial globe, then HRT is half the horizon, H its north, R its west, and T its south point. Z is the *zenith,* the visible highest point above the horizon, standing perpendicularly above the centre of the sphere, while N, the *nadir,* is the invisible lowest point below the horizon; the straight line ZN connecting these points is called the axis of the horizon, and corresponds to the direction of the plummet. The arc ACQ represents the *semi-equator,* ECK the *semi-ecliptic* (path of the sun). The equator ACQ passes through the east and west points (R) of the horizon. The point C, where the ecliptic and equator intersect, is called the *vernal equinox.* The spherical angle ACE, or KCQ, gives the amount of inclination of the ecliptic to the equator, that is, the obliquity of the ecliptic, 23° 27′, measured also by the arc AE or QK. The visible point N, everywhere 90° distant from the equator ACQ, is the *north pole,* the invisible one N″, directly opposite, is its *south pole;* the visible point, P, distant from N about 23° 27′, and 90° distant from every point of the ecliptic, is the north pole of the ecliptic, P′ its corresponding and invisible south pole.

Let S′ be the place of any star in the celestial sphere; and from the zenith Z, draw through the star S′ the arc ZS′T′ of a great circle, perpendicular to the horizon HRT, then the circle of which ZS′T′ is only the fourth part is the *vertical circle* of the star S′; and the arc T′S′ the *altitude* of this star, which is expressed in degrees, reckoning from the horizon; finally the arc ZS′ is the *zenith distance.* In the horizon the altitude is 0° and the zenith distance 90°, while in the zenith the altitude is 90°, and the zenith distance 0°. The arc TT′ of the horizon lying between the meridian and the quadrant ZS′T′ of the vertical circle passing through the star S′ is called its *azimuth,* also measured by the spherical angle T′ZT. The azimuth is reckoned from 0° to 180°, positively from the south point T, eastwardly as far as the north point H, and negatively from T to H, in the opposite direction by the west; as is very evident, the azimuth and altitude of a star completely fix its position in the celestial sphere with respect to the horizon.

If from the north pole, N, of the equator an arc, NS′Q′, be drawn through the star S′, perpendicular to the equator, the circle of which NS′Q′ is the quadrant is called the *declination circle* of the star, and the arc Q′S′ the *declination.* This is called *north* or *south* as the star is north or south of the equator, consequently as it stands in the northern or southern hemisphere of the heavens. The declination is estimated in degrees from the

equator; at the equator being 0°, and at either of its poles 90°. The part CQ′ of the equator ACQ, lying between the vernal equinox C, and the declination circle NS′Q′ of the star S′, is called the *right ascension* of this star; it is reckoned from the vernal equinox C, around the equator from west to east, varying from 0° to 360° (or from 0 to 24 hours), and is expressed in these degrees (or hours). By means, then, of the right ascension and declination of a star, we fix its position in the heavens for a long interval of time, with respect to the equator.

Draw from the pole, P, of the ecliptic, ECK, through the star S′, an arc PS′K′, cutting the ecliptic at right angles, then the great circle of which PS′K′ is only the quadrant, is called the *circle of latitude* of the star S′, and the arc K′S′, the *latitude* of this star. This is *north* when the star is above the ecliptic, as in the figure, and *south* when it is below. The latitude is estimated in degrees from the ecliptic; at the ecliptic it is 0°, at either pole 90°. The part CK′, of the ecliptic ECK, lying between the vernal equinox C, and the circle of latitude PS′K′ of the star S′, is called the *longitude* of the star. It is estimated on the ecliptic from west to east, and commences with the vernal equinox, expressed in degrees from 0° to 360°, or in terms of the 12 signs of the zodiac. The latitude and longitude of a star completely determine its position on the celestial sphere with respect to the ecliptic.

The arc HN of our figure represents the height of the pole N above the horizon HRT, that is, the *altitude of the pole;* and the arc TQ the height of the equator ARQ (on the meridian), above this horizon HRT, or the *altitude of the equator.* The altitude of pole and equator for the same place of observation, are together equal to 90°. The spherical angle Q′NQ, having the north pole, N, for its vertex, or the corresponding arc QQ′ of the equator, is called the *hour angle* of the star S′.

3. The following is a very satisfactory proof among many well known ones, of the spherical shape of the earth. Suppose an observer (*fig.* 8) stationed at a particular point, S, from which a ship sails off in a straight line. At a short distance the whole of the vessel will be visible to the water-line; with increasing distance the ship decreases in apparent height, but is visible to the water's edge. After reaching the horizon at B, there is not only a still further decrease in apparent size, but a disappearance of part of the vessel itself, beginning with the hull. At C only the sails and masts are visible; the appearance presented is represented by *c.* From a higher point T, however, whose horizon passes through D, the hull of the ship will be again visible. The distance still increasing, the lower sails seem just to sink into the water, as at *d,* and finally to disappear entirely. The distinctness with which the summits of the masts are observed, just before their disappearance, must carry home the conviction, that but for the intervening segment, ABCDE, of the sea, the actual distance, SE, is not so great as to prevent an equally perfect view of the whole.

The most important Points, Circles, and Terms of the Terrestrial Sphere.

4. Spherical astronomy determines certain points and circles, as well on the terrestrial as on the celestial sphere. If, for instance, in *fig.* 12, C represent the centre of the earth, and NCS its axis of rotation, then, N,S, are the poles of the earth, QE the terrestrial equator, and AB the parallel of latitude of the place of observation, A, on the surface. Consequently the straight line, AP, parallel to SCN, is that direction in which the visible pole, P, of the heavens, is seen from the place of observation, A. The line AZ, a prolongation of a radius of the sphere, is the direction of the zenith from the observer at A. Furthermore, let NAES be the meridian of A; NGS, a fixed meridian, as the meridian of Paris; then, GE, or the spherical angle, GNE, is the (geographical) longitude of A, and EA, or the angle ECA, the (geographical) latitude. (For further particulars respecting geographical longitude and latitude, see Section 10.) Finally, if *ns* be a plane, tangent to the earth's surface at A, it will constitute the visible apparent horizon of the place; and the straight line, *n*A*s*, produced by the intersection of this plane with the meridian, will be the meridian line of A, so that for A, *n* will be the north, and *s* the south pole of the horizon.

Miscellaneous Considerations respecting the Apparent Rotation of the Celestial Sphere, and the attendant Phenomena.

5. A careful examination of the phenomena exhibited in the apparent daily rotation of the starry heavens, shows that in respect to this rotation, the size of the earth may be considered as entirely insignificant, that is, the observer can be supposed to be situated in the centre of the earth; an assumption very allowable when we reflect on the immense distance of the fixed stars from the earth. Let *pl.* 6, *fig.* 13, represent the celestial sphere, *i*, the observer, Z, his zenith, N, his nadir, then will the circle, H*w*O*e*H (whose poles are N and Z), be the celestial horizon; P*p* represent the poles of the heavens, the circle, HZONH, the meridian, and HP, the altitude of the pole for the observer at *i*. This will be readily seen by referring to what was said on the subject in § 2. The circle, E*w*Q*e*E, perpendicular to the axis, P*p*, will be the equator, in which the vernal equinox occurs at ♈. Then, as already explained in *fig.* 2, the arc, ♈T (*fig.* 13), will be the right ascension, TS the declination, and PS the polar distance of the star, S, projected in the equator by the declination circle, PST*p*; BD will also be the diurnal circle (parallel of declination) described by the star in its apparent motion about the pole, P. The circle, ZM, perpendicular to the horizon, is the vertical circle; the arc, HM, the azimuth; MS, the altitude, and ZS the zenith distance of the star, S. Finally, the points, H, *w*, O, *e*, are respectively the north, west, south, and east points of the horizon.

If H*h* and O*o* represent small parallels of declination, touching the north point of the horizon at H, and the south point at O, then H*h* will be the circle of *perpetual apparition*, between which and the visible pole P the

stars never set; and O*o*, the circle of *perpetual occultation*, between which and the invisible pole *p* the stars never rise. All stars situated between these two circles will be sometimes visible and sometimes invisible. Thus, the star S will be seen when in that part, AB*a*, of its diurnal circle above the horizon, and will be invisible when in the portion AD*a*. Furthermore, the same star will, in the diurnal rotation of the heavens, come back to the same meridian every twenty-four hours, and consequently as the daily rotation of the heavens is uniform, the interval of sidereal time between the arrival of the star at the meridian of two different places, may be expressed by the difference of longitude of the two places. On the other hand, the interval expressed in the sidereal time between the arrival of two different stars at the same meridian, is measured by their difference of right ascension, so that here we find one reason for dividing the equator into both degrees and hours. We find, also, from an inspection of *figs.* 13 and 2, *pl.* 6, that the altitude of the pole at any place is its geographical latitude, and that the sum of the altitudes of the pole and the equator is always for the same place equal to 90°. Likewise we find that every star attains the greatest height above the horizon at its *culmination*, and that all stars lying within the circle of perpetual apparition, cross the meridian twice above the horizon, once above the pole, and once below it; the one being the upper culmination or transit, the other the lower.

The Apparent Course of the Superior and Inferior Planets.

In the Copernican system, the *inferior* planets, Mercury and Venus, which are nearer the sun than the earth, are distinguished from the *superior*, Mars, Vesta, Astræa, Juno, Ceres, Pallas, Jupiter, Saturn, Uranus, and Neptune, which are more remote. This distinction is very proper, as the *phenomena* attending the courses of the inferior and superior planets, are in many respects essentially different from each other. The reason is, that we view the planets from our earth, which itself revolves around the sun at a different rate from the rest, and therefore we see them at very different distances. We observe therefore not the true, but the apparent courses of the planets, which will now be explained. It must ever be kept in mind, however, that the fixed stars being at almost an infinite distance from our earth, their rays must always reach it in parallel lines. In the first place, to illustrate the *apparent* course of an *inferior* planet, let ACEG, in *fig.* 24, represent the orbit of Venus, *acegi* that of the earth, and S the sun. Since the distance of Venus from the sun is about three-fourths that of the earth, and since she traverses her orbit in 7½ months, then, if in *fig.* 24 we divide her orbit into 5, and that of the earth into 8 equal parts, one of these will represent the space traversed by each in 1½ months. If, when Venus is at A, the earth is at *a*, the former is said to be in *inferior conjunction* with the sun (♀ ☌ ☉), that is, on the same side of the sun with the earth. Her apparent diameter is here the greatest, although actually invisible (*fig.* 21); at the expiration of three-fourths of a month, Venus is at B, and the earth at *b*.

The former has consequently *retrograded*, since, taking the fixed direction of the star *s* as a line of reference, Venus to the observer on the earth appears to the right of the star, which is seen in the direction *bs*, parallel to A*s*. It is also evident that Venus has become a *morning* star, since when the observer at *b* looks towards the sun, he sees the planet on the right of the sun. Hence Venus is seen in the eastern horizon before the rising of the sun. *Pl.* 6, *fig.* 21, represents her at this time, crescentic, and with two digits illuminated.

A month and a half after inferior conjunction, the fixed star in whose vicinity Venus was seen when the earth was at *b*, will be seen in a direction parallel to B*b*, from the earth at *c*; consequently Venus will be seen in the direction C*c*, to the left or eastwardly of this star. Hence, it follows that the apparent motion of Venus has again become *direct*. It will also be seen from *fig.* 24, that the angle *sc*S, formed by lines drawn from the earth to the sun and the planet, is larger than the former angle, S*b*B; we accordingly say that the *elongation* of Venus has increased. The illuminated part of her disk has (as seen in *fig.* 21) increased to about four digits; her apparent diameter, however, sensibly diminishes. This elongation must be greatest at the time when the earth (*fig.* 24) is at *d*, and Venus at D, which is the case about $2\frac{1}{2}$ months after inferior conjunction; and this greatest elongation is equal to the angle D*d*S. Venus then (*fig.* 21), like the moon in her last quarter, has half of her disk, or six digits, illuminated.

Half a year after inferior conjunction, when the earth is at *f*, Venus will have reached F, consequently the elongation of Venus has again become less, since the angle, S*f*F, expressing this elongation, is evidently less than the angle S*d*D. Venus, then, during this time has approached the sun, has become fuller (*fig.* 21), but nevertheless smaller, although still the morning star (*fig.* 24). Three months after, the earth is at *h*, and Venus at H; the latter has therefore reached *superior conjunction*, that is, is on the opposite side of the sun from the earth. Her apparent diameter is now the least, and her entire disk (*fig.* 21) illuminated, although invisible. At a later period she appears in the evening sky as the *evening* star, and exhibits the same phases (*fig.* 21) as before, but in an inverted order. Her apparent diameter also increases.

To illustrate the course of a superior planet, let S (*fig.* 25) represent the sun in the centre of the earth's orbit, *abcdefgh*. Let that of Mars be ACEGJLN. The earth revolves in twelve, and Mars in about twenty-three months, about the sun. If, therefore, the original positions of the earth and Mars were at *a* and A, at the expiration of 1, 2, 3, 4, &c., months, the earth will have reached the points *b*, *c*, *d*, *e*, &c.; and Mars B, C, D, E, &c., respectively. When the earth was at *a*, and Mars at A, the latter was in *opposition* to the sun (☌☉), and the stars in the vicinity of Mars must show themselves in the direction *az*. The motionof all the planets from A to B is called direct; consequently Mars has a *direct motion* when advancing from the stars observed in the direction *az*, towards the left, and a *retrograde* motion when moving towards the right. *Pl.* 6, *fig.* 25, shows also that when the earth goes towards *b*, and Mars towards B, the motion of the latter must be retrograde,

because he is observed to the right of the stars at *z*, seen in a direction, *by*, parallel to *az*. Therefore Mars, at the time of opposition, retrogrades.

After the earth has arrived at *b*, Mars is at B, and consequently no longer exactly opposite to the sun, S; but as the stars seen in the direction *by* culminate about midnight, he will then have passed the meridian and will be near his setting, and consequently will be seen in the evening sky.

Two months after opposition, the earth being at *c*, and Mars at C, the retrograde motion of the latter will have ceased, since the straight lines connecting *b*, B and *c*, C, are nearly parallel; consequently to an observer at the earth, the planet will appear *stationary* for some days. At a later period the motion of Mars will be direct. Two months later, Mars, still moving direct, will be at D, and the earth at *d*, so that now the lines *c* C, *d* D, form the angle C*d*′D. It is evident that the directions *d*S, *d*D, from the earth to the sun and to the planet, form nearly a right angle to each other, and consequently that about this time Mars at sunset must be near the south, and must set about midnight.

At the end of the tenth month, when the earth is at *g*, Mars has not completed half his apparent course in the heavens, as shown by his not having reached a point opposite to the stars seen in the direction *gx*. The distance of Mars from the sun, however, is apparently only the angle G*g*S; as at this time an observer at *g*, looking towards the sun and planet, sees the latter to the left or eastward of the former. Mars must appear in the evening sky, after sunset, and evidently much smaller than at time of opposition.

At the expiration of a full year, the earth being at *h*, and the planet at H, the straight line, *h*H, shows that Mars has completed rather more than half the apparent circuit of the heavens, since the stars in the direction *z* stand nearly opposite to him. Consequently the *conjunction* of Mars with the sun (♂ ☌ ☉) has not yet taken place, as, from an inspection of *fig.* 25, it will be seen that the sun still appears to the right of Mars or H.

Two months later Mars is seen early in the morning sky, for since from *i*, the position of the observer, the planet is seen to the right of the sun, at I, he must evidently rise before the sun. By continuing this consideration, with the assistance of *fig.* 25, we shall soon find that Mars, shortly before his new opposition, again becomes retrograde, and that the phenomena before observed must all succeed each other again in the same order.

From all that has preceded it follows, without further explanation, that the inferior planets have an inferior and a superior conjunction, but no opposition; that the superior planets have a conjunction and an opposition, never two conjunctions; and, finally, that while the inferior planets are never visible in the heavens at midnight, the superior may be seen at any hour of the night.

The Moon; her Revolution around the Earth; Phases of the Moon; the Moon's Nodes.

7. Our earth, in her yearly course about the sun, is accompanied by a satellite, the moon, which revolves around the earth in about a month, and in little more than four weeks wanders through the whole zodiac. We need only observe the moon for a few hours, on several successive clear evenings, to satisfy ourselves that while, with the other stars, she follows the diurnal motion from morning till night, she has a peculiar motion of her own, from west to east, advancing daily a little over 13 degrees among the fixed stars of the zodiac. This peculiar motion of the moon is the result of her revolution about the earth; and for the same reason, being an opaque body illuminated by the sun, she is exhibited in all possible shapes (phases). The four principal of these are, the *new* moon, the *first quarter*, the *full moon*, and the *last quarter*. The new and full moon are known as the *syzigies*; the first and last quarters as the *quadratures*. *Pl.* 6, *fig.* 19, offers an intelligible illustration of the various phases of the moon, depending on her different position with respect to the sun and earth. Let *abcd* be the earth placed in the middle of the moon's orbit, NEVLN, and S the sun, whose distance, S*a*, from the earth is supposed to be so great that all his rays are parallel to the line SNV. Let the moon be at N$\beta\gamma\alpha$, or between the earth and sun, her dark side, $\beta\gamma\alpha$, will then be turned to the illuminated side (*dac*) of the earth. At this time the moon is *new*, and being above the horizon in the day time, is invisible. Compare *pl.* 10, *fig.* 5. Two or three days after this time, the moon, moving in her orbit in the direction of the arrow (*fig.* 19), is seen soon after sunset, in the evening sky, as a narrow crescent, which soon sets. This crescentic shape of the moon becomes broader, and she sets later every day, and removing constantly from the sun, she shines through the first hours of the night. In about seven days the moon will have reached L$\pi\nu\mu$, or the *first quarter*, and to an observer at *d*, or the boundary between day and night, will be seen to the left of the sun, as a semicircular disk, with the straight edge to the left or east: the moon now culminates about six o'clock in the evening (see *pl.* 10, *fig.* 5), and sets about midnight. From this time, the outline which from new moon to the first quarter was concave, becomes convex; the moon shines longer, and sets after midnight. In about seven days she will have reached V$\lambda\varkappa\eta$, and become full, standing directly opposite the sun, behind the earth; her illuminated half, $\lambda\varkappa\eta$, consequently, to the dark side, *dcb*, of the earth, appears as a full circle, which rises in the east as the sun sets in the west, culminates at midnight, and sets in the west at sunrise. The moon now rises about an hour later each night, and gradually loses the illumination of her right or westerly side, so that the circular disk becomes oval, until, in seven days after full moon, she will have arrived at E$\zeta\varepsilon\delta$, or the last quarter. To the observer at *c*, the boundary between night and day, her illuminated side, E$\varepsilon\delta$, appears as a half disk, to the left or west of the sun, and the line separating the dark and the illuminated portion will be on the west side, while in the first quarter it was on the east. At the last quarter, she rises

about midnight, and crosses the meridian at about 6 o'clock in the morning. Her semicircular disk now begins to become narrower, the straight edge concave, and the moon again assumes, as she approaches the sun, a crescent shape, which is smaller as the interval of time between the rise of the moon and that of the sun diminishes. About seven days after the last quarter, the moon entirely vanishes, again reaching $N\beta\gamma\alpha$, her position about four weeks before. She now becomes new moon afresh, rising and setting with the sun, and her phases follow in the same succession.

8. Since our earth is also an opaque globe illuminated by the sun, we must present the same alternation of phases to an observer at the moon, that the moon presents to us, only in an inverted order. At the time, therefore, of new moon, first quarter, full, and last quarter, our earth must be *full earth*, *last quarter*, *new earth*, and *first quarter*.

The moon, during a revolution around the earth, describes an orbit, cutting the apparent path of the sun (the ecliptic), or the orbit of the earth, to which it is inclined about 5° 8′ 48″, in two points called the moon's *nodes* (*pl.* 6, *fig.* 20). The point in which the centre of the moon cuts the ecliptic in passing from the south to the north, is called the moon's *ascending node*, ☊, or the head of the dragon; and the one produced in passing from north to south, the moon's *descending mode*, ☋, or the dragon's tail. The distance of the moon from the ecliptic is called the latitude, which may be north or south. At the nodes, the latitude is 0°; hence it follows that the sun, moon, and earth (the sun and earth being in the same plane), must lie at all times nearly in the same plane (*fig.* 20), and when the moon is in one of her nodes, that is in the ecliptic itself, then the three bodies—sun, moon, and earth—have their centres in the same straight line.

The ancients observed that the moon's nodes did not remain in the same part of the ecliptic, but continually moved backwards, or from east to west (indicated in *fig.* 20 by the dotted lines). This retrogression takes place in the following manner: one of the nodes of the moon's orbit—the ascending, for instance—retrogrades in such a manner that if it had coincided with the new moon at starting, this coincidence would again happen after an interval of 18 years and 11 days. The moon's node will then be still 11 degrees distant from the position assumed 18 years and 11 days before. But the sun has in the meantime advanced 11 degrees, and consequently stands again in the node; therefore, since the moon is again in the new moon, an eclipse of the sun must occur, just as it did 18 years, 11 days before. However, the coincidence of the new moon with the node does not take place exactly in the same manner. These periods of 18 years and 11 days, supposed to have been called Saros by the Chaldæan astronomers, are known as the periods of Halley, and were employed by the ancients in the prediction of solar and lunar eclipses. The retrogression of the moon's nodes is a consequence of the secular perturbations of the moon's orbit, and at a mean, with reference to the fixed stars, amounts annually to 19° 20′ 29″ (*pl.* 6, *fig.* 20).

The Seasons ; Daily and Yearly Motion of the Sun.

9. The illustration on *pl.* 9, *figs.* 1, 2, 3, serves to elucidate the theory of seasons, and of the daily and annual motion of the sun. The following may be taken in connexion with what is said further on (sect. 26) respecting the annual motion of the earth round the sun.

The *visible horizon* is that circle in whose centre we are supposed to stand, and which bounds our vision, and upon which the heavens appear to rest. The sun is said to *rise* in the morning when it appears above the horizon, as at C, *pl.* 9, *fig.* 2, and to *set* in the evening when sinking below the horizon, as at C′. The sun appears each day to describe a greater or less circular arc, CMC′, above the horizon, and this arc is constantly inclined towards the horizon. *Noon* of a place is that time of day when the sun at M has arrived at its greatest height above the horizon. The *vertical* of a place (Paris in *fig.* 2) is the straight line VT, parallel to the direction of the plumb line. The line RSO is the *meridian line* of Paris, or the direction of a shadow at time of noon at Paris ; the four points, O, G, R, L, are the four cardinal points of the horizon. The sun appears to traverse a part, CMC′, of a circle by day, completed at night in C′NC, beneath the horizon, and the entire apparent circuit of the sun about the earth lasts 24 hours, or an entire day. A careful examination will, however, disclose the fact that the points of rising and setting of the sun, as also those in which he cuts the meridian, vary from day to day, with respect to the horizon of one and the same place. Thus, on 21st December, CMC′ is the day circle of the sun ; GQL that of the 20th March, greater than the preceding, and KUA that of the 21st of June, which is greatest of all. Hence the sun appears to remain stationary for a time, and then to return towards the south, describing anew the arc GQL to the 23d of September, and CMC′ on the 21st of December, as before. Here he appears stationary for a time, and then returns to the north as before. These arcs described by the sun are all parallel to each other : the greatest of them, KUAK (towards the north) is called the *tropic of Cancer*, the least, CMC′NC (to the south) the *tropic of Capricorn*. The two periods of the year in which the sun describes the tropics are called the solstices. The circle described on the 23d September and the 20th March is called the *equator*, and the two periods when the sun describes the equator are called the *equinoxes*. Consequently the sun seems to move north for six months in the year, viz. from December 21st to 21st June, and south for six months, from 21st June to 21st December.

There is still another motion observable in the case of the sun, viz. a daily progression eastward of about a degree, while the fixed stars retain their relative positions unchanged. Since now 1° in space answers to four minutes in time, the sun will return to the same point of the heavens four minutes later each day, which in 90 days will amount to six hours. The imaginary straight line, PF, passing through the centre, S, of the horizon, and about which the sun appears to describe his circles, is called the *axis of the heavens*. Since all parallel circles of the sun are inclined to the

horizon, and the axis of the heavens is perpendicular to their planes, the axis itself will be inclined to the horizon at the angle PSO, or the arc PO. Their two extremities, P, F, are called *the poles*, P being the north pole, F the south. From the preceding it follows, that for all planes between the equator and the poles of the earth, the celestial sphere is *oblique* (*pl.* 9, *fig.* 3), since the equator, the parallels of declination, and the axis of rotation, have an oblique situation with respect to the horizon.

If the observer be situated at the north pole (*fig.* 4), O, then the celestial sphere becomes to him *parallel*, since there the equator and the tropics, as seen in *fig.* 4, are parallel to the horizon. The axis P*p* of the horizon coincides with the axis of the sphere P*p*, and the horizon H*h* with the equator E*e*. Should the sun be situated in the plane of the equator, he will describe the circle SH, or the horizon, his disk being half above and half below it. When, after the expiration of three months, the sun has reached the tropic of Cancer at S″, he will describe the circle S″N, 23° 27′ above the horizon. He will now be evidently above the horizon, and, in fact, so remain for three months longer, gradually returning to the equator. Thus at and about the north pole the day is six months long. As a matter of course the region about the south pole of the earth must have an equal length of night. During the other six months of the year, these conditions are reversed for the two poles. The fixed stars, however, of these regions never set, that is, those of the northern heavens at the north pole, and those of the southern heavens at the south pole, since they describe their circles parallel to the horizon.

Fig. 5, *pl.* 9, shows the position of the points and circles of the celestial sphere to the observer at the equatorial regions of the earth. There the two poles, P, *p*, lie in the horizon, H*h*, and consequently the axis, P*p*, zenith, E, and nadir, *c*, in the equator. The planes of the equator and tropics are perpendicular to the plane of the horizon, whence the celestial globe forms a *right sphere*. The fixed stars all rise and set perpendicularly to the horizon; each one remaining visible for 12 hours, and invisible for a like portion of time. It is very evident that, in the region of the equator, all the fixed stars must gradually come in sight, and that whether the sun describe the circles, S, S′, or S″, they will all be divided into two equal parts by the horizon. In consequence of this, throughout the whole year at the equator, the days and nights will be equal, and of 12 hours each.

The Geographical Latitude and Longitude of a place; Determination of these.

10. An accurate knowledge of the geographical latitude and longitude of a place, that is, its geographical position upon the earth, is of vast importance to mathematical geography and navigation. The *geographical latitude* of a place is the shortest distance of the place from the equator, expressed in degrees, minutes, and seconds. It will, therefore, be northern or southern, as the place lies north or south of the equator. If, through the given place and the axis of the earth, we pass a great circle, cutting the

equator at right angles, it will be the circle of latitude of the place, and that part of the circle intercepted between the place and the equator, will be its geographical latitude, which may consequently range from 0° to 90°. Any place at the equator has a latitude of 0°; at the poles the latitude will be 90°. Now, as the altitude of the poles is equal to the latitude of the place of observation, we know the one when we know the other. For the determination of the altitude of the pole, a knowledge of the mutual situation of the zenith and pole, with reference to the horizon and equator, is necessary, and this can only be obtained by measurement of the altitudes of certain stars. In practice, therefore, the determination of the altitudes of the pole will depend upon the accuracy with which this measurement can be effected. Various methods have been devised to meet the wants of observation, as also the uncertainties which result from the declination of the star employed, its parallax, and refraction, so that the following eight methods of determining polar altitudes have been suggested and followed.

1, By the meridian altitude of the star; 2, by circummeridian altitudes; 3, by two culmination altitudes at the superior and inferior transits across the meridian; 4, by two meridian altitudes in the southern and northern parts of the meridian; 5, by the altitude of the polar star; 6, by equal altitudes of the circumpolar stars; 7, by altitudes of two stars and the observed interval of time; 8, by the observation of a star in its passage through the eastern and western part of the prime vertical.

The *geographical longitude* of a place is the arc of the equator intercepted between the circle of latitude of the place, and the circle of latitude of another place, assumed as a fixed point of reference. The latter circle of latitude is then called the *first meridian*, and the former the meridian of the place whose longitude is to be determined. Since nature indicates no definite line or circle of departure for the determination of longitude, as she has done in the equator for the determination of latitude, it is evident that the position of the prime vertical, and consequently the amount of the longitude, must be entirely arbitrary. This uncertainty has had for its consequence, the assumption of various standards, inconvenient in practice, and very often producing mischievous effects upon the interests of navigation, which, although now palliated, have not been entirely removed. The difference in the estimate of longitude has, however, been hitherto still greater among astronomers than among navigators, although a difference in estimating the longitude among the former, where calculation is appealed to for assistance, is much less troublesome than among the latter. Almost every astronomer counted the geographical longitude from his own observatory. The meridian of Paris has, however, more recently been selected by the astronomers of the continent of Europe, to which almost all observations and geographical longitudes are referred. It is generally customary in astronomy, at the present time, to regard only the meridian difference of two places of observation, or the angle which the meridian or noon circles of the two places bear to each other, at the pole lying nearest to them. This angle is, of course, measured by the arc of the equator lying between the two meridian circles. This difference of geographical longitude is often called the

meridian difference of two places, since it is equal to the difference of time given by two clocks keeping true time, at the respective places of observation. This difference expressed in hours, minutes, and seconds, is converted into degrees, minutes, &c., by being multiplied by 15, and then will be equal to the above-mentioned angle formed by the two meridian circles at the pole, or the arc of the equator contained between these circles.

The measurement of the distance of two meridian circles, however involves greater difficulties than the determination of the altitude of the pole. The meridian difference of two places is determined by the time required by a star, in the course of its apparent daily revolution, to pass from the meridian of the eastward place to that of the western. Should this star be the sun, we can only compare the times which the clocks in the two places show at one and the same moment. For since at each place the clocks are set 0, or 12, at the time the sun passes his meridian, these, if they keep accurate time, must always differ by the same number of hours, minutes, and seconds. There is therefore only needed some means by which the clocks and instruments used at the different places of observation may be compared with each other, and this may be done in two ways; first, by carrying one clock to the other, without changing their rate in the least; or, secondly, by observing the clock time at which some phenomenon visible from both places, and determinable to the seconds, takes place. The difference in time obtained by either of these methods is then the desired meridian difference, or the difference in longitude, of the two places. We may also remark that the first method consists in the employment and application of portable clocks or chronometers. The second, however, consists in the observation, *a*, of eclipses of the moon and of Jupiter's satellites; *b*, of occultations; *c*, of eclipses of the sun; *d*, of corresponding culminations of the moon and neighboring fixed stars; *e*, of lunar distances; and *f*, of gunpowder or other artificial signals. It is not our place here, to go over these different methods separately and circumstantially, nor to explain the mode of calculating the meridian difference desired. It must suffice to examine a little more closely one, and indeed a very simple method, namely, to show how from observations of the eclipses of one of Jupiter's satellites in two places, the difference of their geographical longitude can be obtained. Let, for instance, in *pl.* 10, *fig.* 1, E be the place of one observer, V that of another, both points being on the surface of the earth. Let both observers note by their clocks the time of their place at which the eclipse of any one of Jupiter's satellites takes place, that is, the time when the satellite begins to enter the cone of shadow ending at x. We will now assume that the time at E is 8 o'clock and the time at V is 10 o'clock, the difference of these two periods amounts to 2 hours 30°, therefore V is 30° east of E.

Unfortunately, the moments (beginning and end) of an eclipse of one of Jupiter's satellites cannot be so readily determined as that of the moon, on account of the unequal illumination and magnifying power of the different telescopes, as also the different acuteness of vision of different observers. Consequently, the meridian difference deduced will not be accurate, or at any rate not reliable; while the other methods admit of greater precision.

The Fixed Stars; their Size, Number, Arrangement, and Distances.

11. By *fixed stars* is to be understood all those stars which are neither planets, nor moons, nor comets, deriving the name from the fact of never changing their relative positions when viewed with the naked eye. The fixed stars are the most numerous objects in the heavens, and are divided into eight classes, according to their various apparent sizes and brilliancy. We speak, for instance, of stars of 1st, 2d, 3d, 4th, 5th, 6th, 7th magnitude, so that those of the 1st magnitude possess the greatest brilliancy, and those of the 7th are only visible to the very acute naked eye. To the 8th class, that is, to those of the 8th, 9th, 10th, &c., magnitudes, belong all those millions of stars which are only visible through the telescope, hence called *telescopic stars*. The color also, especially in the double stars, is very various.

Although the fixed stars do not change their relative positions to each other, yet they have a common apparent motion, produced by the actual daily rotation of the earth on its axis; in addition to this, the annual revolution of the earth about the sun produces various differences in their position with respect to the sun. Finally, there are other although very minute variations in the position of the stars with respect to the horizon, the equator, the ecliptics, &c., produced by refraction, parallax, precession of the equinoxes, nutation, &c., which will be referred to hereafter.

As the number of the stars is apparently infinite, it must necessarily be impossible for us ever to estimate it. Nevertheless, many astronomers have attempted to determine this approximately, at least with respect to the visible stars. The number of those of the first magnitude is 14, of the second, 70, of the third, nearly 300; that of stars of the 4th and succeeding magnitudes is much greater. The fixed stars stand so close together in many parts of the heavens, that any enumeration of these would be absolutely impossible. We need only examine the milky way through a good telescope, to discover that it consists of an innumerable number of fixed stars. Herschel at one time saw more than 50,000 stars cross the fixed field of his great reflector in a space of 30 degrees, near the club of Orion: at another time, he observed 258,000 to pass his 20 foot reflector in 41 minutes.

Lambert, in his "*Kosmologische Briefe,*" was the first to treat of the distribution and arrangement of stars in the heavens. It is in more recent times, however, since the discovery by Mädler of the central sun of our system of fixed stars, that the first tolerably satisfactory explanation of the arrangement of the stars has been given. With respect also to the distances of the stars, nothing more definite was known than that the nearest of them was so remote as to require six years for its light to reach our earth. Bessel and Struve, however, by means of observations of the particular motions exhibited by the double stars 61 Cygni, and Vega (α) Lyræ, have determined these distances with approximate accuracy. According to Bessel's investigations, the distance between our sun and star 61 Cygni would be traversed by light within ten years.

12. Besides the division of stars according to their apparent size, they are classified as *single, double, and multiple stars, variable and temporary stars,* and *nebulous stars.* These will all be referred to hereafter. Groups of stars which are visible, partly to the naked eye, partly by means of the telescope, are called constellations ; while those in which, even with the aid of the most powerful telescope, the individual stars cannot be made out, the whole appearing as a light nebulous cloud, are called *nebulæ.* Finally, that belt of light formed by innumerable stars, and encompassing the whole heavens, varying in breadth and concentration, exhibiting sometimes one branch, and sometimes two, is called the *milky way.* This passes through the constellations (*pls.* 12, 13) Cassiopeia, Perseus, Orion, Gemini, Argo, Centaurus, Ara, Scorpio, Sagittarius, Ophiuchus, Aquila, Cygnus, and Cepheus. Its two branches unite in Ara and Cygnus.

THE CONSTELLATIONS.

13. For the sake of assisting the memory in recollecting the general distribution and relations of the stars in the sky, they have been divided into *constellations.* Those of the northern hemisphere are represented in *pl.* 12, those of the southern in *pl.* 13. These constellations are groups of fixed stars, whose outlines have been supposed to represent figures of men, animals, and other objects, and to which corresponding names have been given. With the arrangement of new constellations, it becomes necessary to have new names, which may either be derived from the animal kingdom, as done by the ancients, *e. g.* the Giraffe and the Lizard, or names may be selected commemorating important discoveries and inventions in the arts and sciences, *e. g.* the compass, the air pump, and the pendulum clock.

The names of the separate constellations, as given by Hipparchus, are the following :—

a. The Twelve Constellations of the Zodiac.

♈ Aries,	(Ram,)	*Widder.*
♉ Taurus,	(Bull,)	*Stier.*
♊ Gemini,	(Twins,)	*Zwillinge.*
♋ Cancer,	(Crab,)	*Krebs.*
♌ Leo,	(Lion,)	*Löwe.*
♍ Virgo,	(Virgin,)	*Jungfrau.*
♎ Libra,	(Balance,)	*Wage.*
♏ Scorpio,	(Scorpion,)	*Skorpion.*
♐ Sagittarius,	(Archer,)	*Schütze.*
♑ Capricornus,	(Goat,)	*Steinbock.*
♒ Aquarius,	(Water Bearer,)	*Wassermann.*
♓ Pisces,	(The Fish,)	*Fische.*

b. The Twenty-one Constellations of the Northern Heavens.

Cassiopeia,	(Cassiopeia,)	*Kassiopeia.*
Andromeda,	(Andromeda,)	*Andromeda.*
Triangulum,	(Triangle,)	*Nördliches Dreieck.*
Perseus,	(Perseus,)	*Perseus.*
Auriga,	(Charioteer,)	*Fuhrmann.*
Ursa Major,	(Great Bear,)	*Grosser Bär.*
Draco Borealis,	(Dragon,)	*Nördl. Drache.*
Bootes,	(Bootes,)	*Bootes.*
Corona Borealis,	(Northern Crown,)	*Nördl. Krone.*
Cepheus,	(Cepheus,)	*Cepheus.*
Pegasus,	(Pegasus,)	*Pegasus.*
Ursa Minor,	(Lesser Bear,)	*Kleiner Bär.*
Hercules,	(Hercules,)	*Hercules.*
Ophiuchus, or	(Serpentarius,)	*Ophiucus.*
Serpens,	(Serpent,)	*Schlange.*
Lyra,	(Lyre,)	*Leier.*
Aquila,	(Eagle,)	*Adler.*
Cygnus,	(Swan,)	*Schwan.*
Sagitta,	(Arrow,)	*Pfeil.*
Delphinus,	(Dolphin,)	*Delphin.*
Equuleus,	(Little Horse,)	*Kleines Pferd.*

c. The Fifteen Constellations of the Southern Heavens.

Cetus,	(Whale,)	*Wallfisch.*
Canis Major,	(Great Dog,)	*Grosser Hund.*
Canis Minor,	(Little Dog,)	*Kleiner Hund.*
Hydra,	(Hydra,)	*Grosse Wasserschlange.*
Crater,	(Cup,)	*Becher.*
Corvus,	(Crow,)	*Rabe.*
Lupus,	(Wolf,)	*Wolf.*
Orion,	(Orion,)	*Orion.*
Centaurus,	(Centaur,)	*Centaur.*
Argo,	(Ship,)	*Schiff Argo.*
Corona Australis,	(Southern Crown,)	*Südliche Krone.*
Piscis Australis,	(Southern Fish,)	*Südlicher Fisch.*
Lepus,	(Hare,)	*Hase.*
Ara,	(Altar,)	*Altar.*
Eridanus,	(The Po,)	*Fluss Eridanus.*

To these forty-eight constellations of the ancients, there have been added in modern times the following fifty-eight :—

d. The Fifty-Eight Constellations discovered in modern times in the Northern and Southern Heavens.

Antinous,	(Antinous,)	*Antinous.*
Coma Berenicis,	(Berenice's Hair,)	*Haupthaar der Berenice,*
Robur Carolinum,	(Charles's Oak,)	*Karlseiche.*
Columba,	(The Dove,)	*Taube.*
Crux,	(Cross,)	*Kreuz.*
Scutum Sobieskianum,	(Sobieski's Shield,)	*Sobieski's Schild.*
Monoceros,	(Unicorn,)	*Einhorn.*
Camelopardalis,	(Giraffe,)	*Giraffe.*
Sextans,	(Sextant,)	*Uranischer Sextant.*
Canes Venatici,	(Greyhounds,)	*Jagdhunde.*
Leo Minor,	(Little Lion,)	*Kleiner Löwe.*
Lynx,	(Lynx,)	*Luchs.*
Vulpes et Anser,	(Fox and Goose,)	*Fuchs und Gans.*
Lacerta,	(Lizard,)	*Sterneidechse.*
Triangulum,	(Little Triangle,)	*Kleines Dreieck.*
Musca,	(Fly,)	*Fliege.*
Cerberus,	(Cerberus,)	*Cerberus.*
Anser Americanus,	(American Goose,)	*Amerikanische Gans.*
Phœnix,	(Phœnix,)	*Phönix.*
Hydrus,	(Hydra,)	*Kleine Wasserschlange.*
Dorado,	(Swordfish,)	*Schwertfisch.*
Piscis Volans,	(Flying Fish,)	*Fliegender Fisch.*
Chameleo,	(Chameleon,)	*Chamäleon.*
Avis Indica,	(Bird of Paradise,)	*Paradiesvogel.*
Triangulum,	(Southern Triangle,)	*Südliches Dreieck.*
Pavo,	(Peacock,)	*Pfau.*
Indus,	(Indian,)	*Indianer.*
Grus,	(Crane,)	*Kranich.*
Mons Mænalus,	(Mount Mænalus,)	*Berg Mänalus.*
Cor Carolinum,	(Charles's Heart,)	*Herz Karl's II.*
Cervus,	(Reindeer,)	*Rennthier.*
Pica Indica,	(Indian Bird,)	*Indianischer Vogel.*
Taurus Poniatowski,	(Poniatowski's Bull,)	*Stier Poniatowski's*
Quadra,	Square,	*Mauerquadrat.*
Officinum Sculptorum,	(Sculptor's Workshop,)	*Bildhauerwerkstatt.*
Fornax Chemica,	(Chemical Furnace,)	*Chemischer Ofen.*
Horologium,	(Clock,)	*Pendeluhr.*
Reticulus Rhomboidalis,	(Rhomboidal Net,)	*Rhomboidisches Netz.*
Cœlum Sculptorium,	(Graver,)	*Grabstichel.*
Equuleus Pictoris,	(Painter's Easel,)	*Malerstaffelei.*
Pyxis Nautica,	(Mariner's Compass,)	*Seecompass.*
Machina pneumatica,	(Air Pump,)	*Luftpumpe.*
Octans,	(Octant,)	*Seeoctant.*

Watchman,	*Erntehüter.*
Sceptre of Brandenburg,	*Brandenburgisches Scepter.*
Honors of Frederick,	*Friedrichsehre.*
George's Harp,	*Georgsharfe.*
Herschel's Telescope,	*Herschel's Teleskop.*
Balloon,	*Luftballon.*
Printing Press,	*Buchdruckerwerkstatt.*
Electric Machine,	*Electrisir Maschine.*
Log Line,	*Log Leine.*
Compasses,	*Zirkel.*
Ruler and Square,	*Lineal und Winkelmaass.*
Telescope,	*Astronom. Fernrohr.*
Microscope,	*Mikroskop.*
Table Mountain,	*Tafelberg.*
Level,	*Setzwage.*

There are consequently 106 constellations in the heavens, forty-eight old, and fifty-eight new.

Maps of the Stars; Planispheres; Application of the Method of Alignments in Learning the Stars and Constellations.

14. For the sake of more readily learning the constellations and their particular stars, as also for the more certain guidance of astronomers, those delineations on paper of the starry heavens known as celestial maps, or maps of the stars, have been invented. These maps comprehend either the two planispheres, as in *pls.* 12 and 13, and are then called *planispheres*, or they contain single parts of the heavens, and then together form an atlas. The celestial maps of Bayer, Doppelmayer, Goldbach, Flamsteed, Bode, Harding, Schwinck, Riedig, Argelander, and others, are well known. Besides the introduction of constellations, the ancients, particularly the Arabians, ascribed particular names to the brighter fixed stars, as, for instance, in Orion (*pl.* 12), *Bellatrix* and *Betelgeux*, *Capella* in Auriga, *Altair* in Aquila, *Arcturus* in Bootes, *Castor and Pollux* in Gemini, *Marcab* in Pegasus, &c., and in *pl.* 13, *Rigel* in Orion, *Fomalhaut* in Piscis Australis, *Sirius* in Canis Major, *Antares* in Scorpio, &c. Johann Bayer, however, in the beginning of the seventeenth century, introduced a much better and more complete assistant to the memory in recollecting and referring to the stars, by employing the letters of the Greek and Roman alphabets, which convenient notation has since been justly retained. It may be observed in the two charts of the stars, *pls.* 12, 13.

A very easy means of finding and readily learning the most important stars and constellations is afforded by what is called the method of *alignments;* this consists in having straight lines drawn in the chart (*pls.* 12, 13) connecting the single brighter stars, thus forming triangles and quadrilaterals, which are again reconstructed in the sky by imaginary lines drawn between these stars. This will be referred to hereafter.

The Double Stars; Remarkable Collections of Stars; Nebulous Spots and Stars.

15. By *double stars* is meant two stars, generally so near together that to the naked eye they appear but as a single star. There are nevertheless many double stars only visible through the telescope. These may consist of two kinds—*optical*, or apparent, and *physical*, or actual double stars. The first are such as, not related to each other, happen to fall nearly on the same line of vision; the latter are those which, connected in one system, revolve the one about the other. One of these is frequently larger than the other, although sometimes their size is nearly equal. Their colors, however, are always different. The single fixed stars and the optical double stars shine only with a whitish light, verging sometimes on yellow, sometimes on red. The physical or actual double stars, of which alone we here treat, have only been studied within the last few decades. The peculiar motions of these remarkable stars appear to occur according to the Newtonian laws of gravitation, and Savary, Encke, John Herschel, and Mädler, have already determined the orbits of many double stars, as 70 p, Ophiuchus, polar star, γ Andromedæ, ζ Ursæ Majoris, ζ Herculis, &c., as also their periods of revolution, which latter in some double stars amount to a few years, in others to many centuries. Since one of two double stars, as before stated, revolves around the other, it may readily happen that with respect to our earth one may pass before the other so as to cover it completely. This has actually been confirmed by observation. Thus, for instance, stars which once were double are now single, and others which were once single are now seen as double. Consequently the apparent distances of the double stars cannot be otherwise than variable. Struve has published a catalogue of 3112 double and multiple stars, arranged in order, which is thus far the most complete and accurate.

Since the double stars generally present very slight points of light of various distance and distinctness, their observation may serve as the surest test of the excellence of a telescope. Achromatic telescopes, which, for instance, merely exhibit ζ, Ursa Major, or Mizar (*pl.* 12, *fig.* 3), and γ, Andromeda, Alamak (*fig.* 6), as double stars, are only of ordinary power. Those, however, are much better which show as double stars Castor and Pollux, or α Gemini (*pl.* 12, *fig.* 1) and the pole star, or α Ursæ Minoris (*fig.* 9), as also Mesarthim, or γ Arietis (*fig.* 8), and Cor Caroli in Canes Venatici (*fig.* 10). An instrument that shall show γ Virginis (*fig.* 2), α Arietis (*fig.* 5), β Orionis, or Rigel (*fig.* 7), and *Ras Algithi*, or α Herculis (*fig.* 4), as double, is one of extraordinary excellence. The double star Vega, or α Lyræ (*fig.* 11), is probably not really but only optically double, the smaller of the 12 magnitudes being distant about 43 seconds from the principal stars.

16. Among the spots of the northern heavens richest in stars belong the groups figured on *pl.* 12; the *Pleiades*, or the seven stars, *fig.* 12, in the back of Taurus, the *Hyades*, or rain stars, *fig.* 13, in the forehead of Taurus, the little group of stars (*fig.* 14) between the tips, β and ζ, of the

horns of Taurus; the rich region about Vega and Lyra; the so called Lucida Lyræ; the numerous stars about Arcturus (*fig.* 16), in Bootes, and the vicinity of the great remarkable nebula (*fig.* 17) in Orion.

With respect to the nebulous spots and stars, *pl.* 13 (*figs.* 1 to 20) represents twenty of the largest and most beautiful. *Fig.* 1 is a double nebula in Gemini (108° 45′ right ascension, and 29° 49′ declination), consisting of two round nebulæ touching each other, which shine almost like stars. *Fig.* 2 exhibits the double nebula in Coma Berenicis (right ascension 187° 0′, declination 12° 8′), of great brilliancy. *Fig.* 3 gives a view of a small double nebula of right ascension 158° 15′, declination south 17° 55′. *Fig.* 4 is a curiously shaped nebula in Ophiuchus (Serpentarius). *Fig.* 5 represents two nebulous spots touching each other nearly at right angles, of tolerably elliptical shape, to be found in the constellation of Canes Venatici. *Fig.* 6 represents the remarkable annular nebula in Lyra, rt. asc. 281° 45′, N. dec. 32° 49′, whose opening is filled with a second ash-grey nebula the whole appearing like a veil drawn over an almost circular hoop. At 33° 0′ of right ascension and 41° 34′ North declination, in Perseus, is seen a distinct and very eccentric nebula (*fig.* 7) of 4′ length and 40″ breadth, in whose midst is a concentric, also elliptical, space, at whose two extremes two little stars are seen. Still more remarkable is the nebulous spot (rt. asc. 268° 0′, S. dec. 23° 1′) in Sagittarius (*fig.* 8), seemingly split into three pieces; a double star is seen in the midst of the dark interspace *Fig.* 9 gives a view of the extremely remarkable and tolerably large nebula in constellation Robur Caroli of the southern hemisphere, consequently not visible in the northern. A number of minute stars will be observed to shine out from it.

The following may be particularly mentioned among the number of irresolvable planetary nebulæ. The well known great nebula in Andromeda (*pl.* 13, *fig.* 10), visible to the naked eye, of peculiar feebly glimmering light, 30′ in diameter; the stars standing in its vicinity do not appear to belong to it. A nebula (*fig.* 11) occurs in Cetus, similar to the one in Perseus (*fig.* 7), only longer and broader. A curiously shaped elongated nebula (*fig.* 12) is met with in Cygnus, while planetary, entirely round, and brilliant nebulous spots exhibit themselves in Sagittarius (*fig.* 13) and the hand of Andromeda (*fig.* 14). A spot (*fig.* 15) similar to these last is shown in Orion, and a granular nebula, with a very bright spot, in Ursa Major (rt. asc. 127° 45′, N. dec. 50° 49′). But the most remarkable, perhaps, of all is the great nebula in Orion (*fig.* 17), under the middle of the (so called) Jacob's Staff, near the star Θ; distinguished above all the others by its peculiar shape (not unlike the opened jaws of a wild beast), by the curious variety in the distribution of its light, as well as by its great extent. Even the fixed stars in and about it are remarkable for their lustre, and the positions of some of them appear to have a particular relation to the nebula itself. It has been supposed, from a comparison of older figures of this nebula with its present appearance, that it has undergone a decided change, although this is by no means absolutely certain. An almost equally remarkable object is found in the constellation Vulpes (rt. asc. 298° 0′ and

N. decl. 22° 17′), in the shape of a large oval nebulous spot (*fig.* 18), whose major axis is to its minor as 4 to 3. In the two foci are found two circular nebulæ, much darker, and equally illuminated in all parts. *Fig.* 19 represents a curious nebulous figure found in the head of the northern Canis Venaticus. It is a round, bright, central spot, surrounded by a nebulous ring split on one side. Further improvements in the telescope will probably exhibit more clearly the true character of these wonderful objects. The Magellanic Clouds, observed in the southern hemisphere and invisible to us (*fig.* 20), are in like manner highly remarkable appearances of the starry heavens, consisting of isolated clear spots, like separated portions of the Milky Way. According to Horner, who has communicated some observations on these Magellanic Clouds, the greater of them is about as bright as the Milky Way in its brightest part, as near Cygnus, while La Caille was not able to find a single star in them with his 14-foot telescope.

Multiple, Variable, and New Stars.

17. In conclusion, it remains to state that, besides the double stars, there are threefold and fourfold, or *multiple* stars, as also *changeable* and *new stars.* Threefold stars are found, for example, in Orion, under $72\frac{1}{4}°$ rt. asc., and $14\frac{1}{4}°$ N. decl., in ζ Cancer, ξ Libra, 7 Taurus, Ψ Cassiopeia, π Monoceros, Ψ Libra, as also in Lynx, under $97\frac{1}{2}°$ rt. asc. and $59\frac{3}{5}°$ N. declination. Of the fourfold stars Θ Orion is perhaps the most distinguished; it stands very near the darkest part of the great nebula in Orion; ε Lyra is also a fourfold star. Among multiple stars, ζ Orion is known as the most remarkable; it was known by Schröter as a 12-fold, but by Struve as a 16-fold star. The variable stars are also remarkable, that is, those stars whose apparent magnitude does not remain the same. These stars shine within a certain period with various degrees of brilliancy, and it is said that they have a certain period, as, for instance, Algol in Perseus, α Hercules, β Lyra, γ Antinous, δ Cepheus, &c. Nevertheless the periods of several variable stars appear subject to many irregularities. Other stars often vanish entirely, and reappear at a later period, as Mira in Cetus, χ Cygni, and seven stars in Leo, Virgo, Hydra, Corona, and Aquarius.

In addition to all these, stars have sometimes appeared suddenly in regions of the heavens tolerably free from stars, which could not have been there before; such appeared in Aquila in 389, between Cepheus and Cassiopeia in 945, again near the same place in 1264, in Cassiopeia (Tycho's star) in 1572 and 1573, in Ophiuchus, 1604 and 1605, and in Cygnus (Anthelm's star), 1670. Astronomers have not yet been able to frame a satisfactory hypothesis to explain the phenomena which the variable and new stars exhibit in so remarkable a manner.

II. Theoretical Astronomy.

The Circle and Ellipse.

18. In the study of Astronomy a knowledge of the circle and ellipse is absolutely necessary. If a straight line, CD (*pl.* 6, *fig.* 3), make a complete revolution in the same plane around one extremity, C, the other end, D, will describe the *circumference*, DHAGFD, in which each point is equally distant from the *centre*, C. The plane surface inclosed by this circumference is called *the circle*. Every straight line drawn from the centre, C, to the circumference is a *radius;* and every straight line connecting two points of a circumference and passing through the centre is a *diameter* (AB). All radii are equal to each other, so also are all diameters. Any straight line connecting two points of the circumference, not passing through the centre, is called a *chord* (EF). It divides the circle into two unequal parts, EAHDBF and EGF, of which the latter, as the smaller, is called the *segment*. The diameter, AB, on the contrary, divides the circle into two equal parts, AHDB and AEGFB, called *semicircles*. The angle, DCB, formed by two radii, DC and CB, at the centre of the circle, is called a *central angle;* the surface, BCD, inclosed between a central angle and the arc of the circumference inclosed between the radii, is called a *sector*. Finally, a straight line outside of the circle and touching the circumference in only one point, is called a *tangent*, JK.

An ellipse, ADBEA (*pl.* 6, *fig.* 4), is a complete curve, possessing the peculiarity that, if two straight lines be drawn from certain points, SS′, in its area, called the *foci*, to any point in the circumference, their sum will be equal to the sum of similar lines drawn to any other points. Thus $SP + S'P = Sp + S'p$. This same sum will also be always equal to the length of the greater axis, AB. The lines SP and S′P (or also S*p* and S′*p*) are called the *radii vectores* of the point P (or *p*). The straight line, DC, passing through the centre, C, at right angles to the major axis, AB, is called the *minor axis*. CS or CS′ is called the eccentricity of the ellipse. Should this ellipse represent the orbit of a planet in one of whose foci the sun is situated, then if the planet be situated at P or *p*, the line SP or S*p* will be the *radius vector* of the planet.

Parallax; Horizontal Parallax and Parallax in Altitude; Parallax of a Place.

19. *Fig.* 5 will serve for the explanation of what astronomers mean by the word *parallax*. Let ABD represent the meridian circle of a place of observation, A; C the centre of the earth; let HJ be a part of the infinitely distant sphere of the heavens; finally, let the moon be at M. The line HCD represents the true horizon, *a*A*a*′ the apparent horizon of the place, A. If the moon be supposed to stand in the horizon at M, it will be

referred by an observer at A to that part of the celestial sphere occupied by the star *a*. From the centre of the earth it would be referred in the direction CM to the celestial sphere at *b*. The angle AMC, or *a*M*b*, will represent the difference of the two directions ; and this angle, AMC, is called the *parallax* of the point M, or its *horizontal parallax*, since M is situated in the horizon. Let the moon now stand higher in the heavens, as at M′, then from A she will be seen in the direction AM′*c*, consequently referred to the point *c* of the heavens ; and from C, the centre of the earth, in the direction CM′*d*, referred consequently to the celestial sphere at *d*. The angle CM′A = *c*M′*d* will be the difference of the two directions CM′ and AM′ ; and CM′A will be the parallax of M′, more definitely its *parallax in altitude*, because M′ is situated a certain distance above the horizon. Let the moon now be situated at M″, or in the direction of the zenith, *e*, of A, then the moon, M″, will be referred to the heavens at *e ;* the two lines of sight will coincide, and they will form no angle, so that for heavenly bodies situated in the direction of the zenith, the parallax in altitude vanishes or becomes zero. We find, also, by examining the figure that the parallax is at its maximum in the horizon, diminishing with the angle of elevation until in the zenith it is zero.

Suppose now a second place of observation, E, lying in the same meridian, and the moon to be situated at M′ ; then from A she will be seen in the direction AM′*c*, consequently referred to *c*, and from E in the direction EM′*d*′, and referred to *d*′. The angle EM′A gives the difference of the two directions EM′, AM′. This angle EM′A, or the corresponding arc *cd*′, is called the *local parallax* of the star at M′ for the two places A and E. Hence it is clear, that for the same altitude of the same star, its local parallax will be less as the distance of the two places of observation on the same meridian is less.

The Heliocentric and Geocentric place of the Planets ; their Commutation and Annual Parallax.

20. The motions exhibited by the planets are not so simple as the apparent daily motions of the fixed stars, as above considered. This results from the fact of their having two motions, of which one is diurnal, in common with the fixed stars, from east to west, and the other an orbitual motion from west to east. Add to this, that the planets are not, like the fixed stars, almost infinitely distant from us, and that therefore it makes a material difference whether their revolutions be observed from the sun or the earth. The place of a planet, as seen from the sun, is called its *heliocentric place ;* its position as seen from the earth, is the *geocentric place*. *Fig.* 14, *pl.* 6, is intended to illustrate these terms. Let S be the centre of the sun, the circle described through T the orbit of the earth, that through P the orbit of any superior planet, and the extreme circle, the ecliptic ; the exterior and interior circles lying, of course, in the same plane, which may be the plane of the paper. Furthermore, let the earth be at T, the planet at P, and let

Υ be the vernal equinox. The arrows give the direction of the motions of the earth and planet, as also the order of the signs of the ecliptic. The planet P will now be seen from the sun, S, in the direction Sp; the angle ΥSp, or the arc Υp, will consequently be the *heliocentric* longitude of the planet, and the angle ΥST, or the arc Υt, the *heliocentric longitude* of the earth. From the earth T, the planet P will evidently be seen in the direction Tp'. It is further allowable, on account of the almost infinite distance of the fixed stars, to consider the line TA parallel to SΥ as meeting in the same point of the celestial sphere, and consequently A and Υ as coinciding. The angle ATp' then, or the arc $\Upsilon p'$, is the *geocentric longitude* of the planet; and since the plane of the planet at P has a certain inclination to the common plane of the inner and outer circles, the angle PSQ, or the arc PQ, will represent the *heliocentric latitude* of the planet, if the arc PQ be supposed drawn from the planet P, perpendicular to the plane of the earth's orbit. Finally, the angle PTQ will be the *geocentric latitude* of the planet. The angle PTS, at the earth, will be the *elongation* of the planet, or its apparent angular distance from the sun, this elongation being (*pl.* 6, *fig.* 14) equal to the heliocentric longitude of the earth, + 180°, diminished by the geocentric longitude of the planet. From the preceding it follows that p will be the *heliocentric*, and p' the *geocentric* place of the planet, with respect to the ecliptic. We can speak in the same manner of the heliocentric and geocentric position of a planet with respect to the equator, and consequently of the heliocentric and geocentric right ascension and declination.

We have still to speak of the *commutation* and the *annual parallax* of a planet. The commutation is the angle PST (*fig.* 14), at the sun, S, obtained by deducting the heliocentric longitude of the earth from the heliocentric longitude of the planet. The annual parallax is the angle TPS, at the planet P, obtained by deducting the heliocentric longitude of the planet from its geocentric longitude. It is very evident that we can never speak of the geocentric place of the earth.

Some other Important Elements in the Theory of the Planetary Motions.

21. The *mean anomaly*, the *true anomaly*, the *perihelion distance*, and the *aphelion distance*, are far more important to the theory of the planetary motions than the commutation and the annual parallax. If, for instance, m (*fig.* 15) be the *mean place* of a planet, p the *true place*, then rays, Sm, Sp, from the sun to these two positions will form, with respect to the major axis AP, of the elliptical planetary orbit, the angles mSP', pSP, which are respectively called the *mean* and the *true anomaly* of the planet. Their great importance consists in this, that the mean anomaly expresses the uniform or the *mean motion in the circle*, while the true anomaly expresses the *true motion in the ellipse*. The true anomaly, or the angle PSp, consists of two parts, angles mSP' and mSp. This latter angle, mSp, however, which evidently is the difference between the true and mean motions of the planet, is called the

equation of the orbit, and is one of the most essential elements in the theory of the planetary motions. For, knowing the equation of the orbit, the sum of the mean anomaly and the equation of the orbit gives the true anomaly, and consequently the true—that is, the elliptic longitude of a planet in its orbit. In conclusion, P is the *perihelion* and A the *aphelion* of the planet, in which points it will be respectively at its least and greatest distances from the sun.

Eclipses of the Sun and Moon.

22. We come now to eclipses of the sun and moon (*pl.* 6, *fig.* 18). The full moon at times loses gradually its light in a manner just as if a blackish grey disk were drawn slowly over its face, moving from left to right, and passing off on the opposite side. An eclipse of the moon is then said to take place, which, as it only occurs when the moon is full, and, indeed, when the full moon is in or near the straight line connecting the centres of the sun and earth, is of easy explanation. The earth, as an opake globe illuminated by the sun, must throw a shadow into space on the side opposite to the sun, this shadow being conical, and longer than the distance of the moon from the earth. The moon must also, as a body likewise illuminated by the sun, lose partly or entirely her light by passing partly or entirely into the shadow of the earth. If the moon's orbit lay in the plane of the ecliptic, it is clear that an eclipse would occur at every full moon, which experience shows not to be the case. We learn above, section 8, that the path of the moon is inclined 5° 8′ 48″ to the ecliptic; the full moon passes for the most part, therefore, above or below the earth's shadow, and it is only when the full moon happens in or near one of the moon's nodes, that the moon can encounter the earth's shadow. As the moon's nodes do not remain in the same part of the ecliptic, it is very evident that the eclipses of the moon (and sun) must take place in different years and months, so that definite periods arise, after whose lapse the eclipses again occur in the same months.

Astronomy teaches the conditions necessary for the occurrence of an eclipse. Should the full moon be situated at a distance from one of its nodes of less than $12\frac{1}{2}°$, the moon may be partially eclipsed. Should the distance be less than $9\frac{1}{2}°$, and greater than $5\frac{1}{2}°$, a partial eclipse must take place. The eclipse will be *total*, that is, the moon will be entirely obscured, when the full moon takes place at less than $5\frac{1}{2}°$ from one of the nodes. A merely partial eclipse of the moon cannot last more than 2 hours and 18 minutes; the time of a partial, and at the same time total eclipse, may amount to 4 hours and 24 minutes. Astronomers are accustomed to determine beforehand the particular circumstances of an eclipse of the moon, as the beginning, the middle, and the end of the obscuration, the countries in which it will be visible, as well as the size of the eclipsed portion. The latter is given in digits (1 digit $= \frac{1}{12}$ of the diameter of the disk). Unfortunately, however, the period of beginning and ending of an eclipse cannot

be exactly determined, as the earth's shadow falling on the moon (*pl.* 6, *fig.* 18), like any other shadow, is not bounded by sharp outlines, but fades off into light, and in every eclipse there is also distinguished a full shadow or *umbra*, and a half shadow or *penumbra*. From the preceding it is clear that an eclipse of the moon is not merely an apparent, but a real occurrence. Consequently, the inhabitants of all those portions of the earth in which the moon shines at the time of the eclipse, see every particular of the eclipse in the same manner and at the same time, even if the local times of the places should be different.

Sometimes a black disk is seen to pass gradually from right to left before the sun. But as this phenomenon is not seen alike at all places above whose horizon the sun may be at the time, since in some countries the sun is covered more or less than in others, or not at all, it is evident that this phenomenon cannot be the result of an actual obscuration of the sun. It is rather produced by the moon (*pl.* 6, *fig.* 18, and *pl.* 14, *fig.* 56), since it only happens at the time of new moon. It has been observed that these uncommon phenomena, called eclipses of the sun, occur only when the new moon happens to be in or near one of its nodes. By its intervention between the earth and sun, it then hides the view of the latter entirely or partly from the former. The phenomenon exhibited, is precisely as if the sun in a cloudless sky were covered for a time by a little black cloud passing over his disk. As the shadow of the cloud moves along in the plain beneath, in the direction in which the cloud is driven by the wind, and conceals from the observer whom it overtakes the sight of the sun, while others out of the bounds of the shadow still see that luminary; just so the shadow of the moon moves along over the earth's surface from west to east in the direction of the moon's motion around the earth, conceals from the countries traversed by it the view of the sun, and produces the phenomenon of eclipse. All regions not thus traversed see the sun as usual.

Eclipses of the sun are distinguished into *partial*, *total*, *central*, and *annular*. An eclipse is *partial*, when the moon covers the sun only in part; *total*, when this covering is complete. When the moon's disk is apparently smaller than that of the sun and stands directly before him, the eclipse is annular. A total or annular eclipse is central when the centres of the sun and moon's disk coincide. For the entire earth's surface, a partial eclipse can last about 7 hours; one, partial and total, 4 hours and 48 minutes; but for a given place on the earth's surface, a total eclipse cannot continue more than $4\frac{1}{2}$ hours at the very utmost. The calculation of the separate circumstances of an eclipse of the sun becomes, therefore, more difficult and circumstantial than those of the moon, since, as before mentioned, the former are not actual occurrences like the latter, but only apparent phenomena, whose shape, size, and duration depend upon the place of the observer on the earth's surface.

An eclipse of the sun cannot take place when the new moon is more than 1° 35′ distant north or south of the ecliptic: 1° 24′ is the minimum distance that the moon can pass near the sun without causing an eclipse. A north or south latitude of the moon less than 1° 24′ at time of new moon always

produces an eclipse of the sun, whose extent, as in the case of the lunar eclipses, is given in digits (12 digits = diameter of the sun's disk). Hence it follows that the limits of possible occurrence of eclipses are much more extended in the case of the sun than in that of the moon. Consequently it follows that, for the whole surface of the earth, the former are much more frequent than the latter, for on an average there may happen within 18 years 41 eclipses of the sun and only about 29 of the moon. At least two eclipses of the sun must occur annually, because the sun every six months comes in the neighborhood of the moon's ascending or descending node; while eclipses of the moon may be wanting for an entire year. But for any particular place on the surface of the earth, as, for instance, Leipzig, the visible eclipses of the moon are thrice as numerous as those of the sun. It may be assumed that every part of the earth's surface may expect a partial eclipse of the sun within every two years, and a total within 200. Sometimes, though but rarely, the number of solar and lunar eclipses for the entire earth may amount to seven in a year, occurring then in January, July, and December.

By the actual observation of a solar eclipse, its beginning and end can be determined much more accurately than the same circumstances of a lunar eclipse. For this reason observations on the former are much more certain assistants in determining geographical longitude.

The course and extent of the moon's shadow over the surface of the earth during a total or annular eclipse of the sun is shown by *fig.* 56, *pl.* 14. It represents also the manner in which the principal circumstances of such a phenomenon are usually delineated on a map.

The Planetary Systems of Ptolemy, Copernicus, Tycho, and the Egyptians. Tabular Exhibition of the Most Important Features of our Planetary System.

23. By a *planetary system*, the ancients understood the disposition and course of seven planets with respect to our earth. Since the time of Copernicus, however, by the *solar system*, in the ordinary acceptance of the term, is meant the disposition and mutual arrangement of 14 primary and 19 secondary planets about our sun, which system is commonly termed the *Copernican*. By a solar system, taken generally, is understood any fixed star of the heavens, as a sun, with the spheres revolving about it as planets. Since astronomy has been pursued as a science, four planetary systems have had the greatest share of attention, being, in order of time, that of *Ptolemy*, the *Egyptians*, *Copernicus*, and *Tycho*.

According to Ptolemy (an astronomer of Alexandria, living about A.D. 150), the earth (*pl.* 7, *fig.* 1) stands immovably in the centre of 12 circles. From the earth outwards the seven first circles represent the paths of the following bodies as planets, and in the following order:—the *Moon; Mercury; Venus;* the *Sun; Mars; Jupiter:* and *Saturn*. The eighth circle, *e*, represents the path of the fixed stars; the ninth, *d*, and tenth, *c*, called

the first and second crystal heavens, were intended to serve in explaining the phenomena produced by precession (precession of the equinoxes); the eleventh circle, *b*, called primum mobile, was supposed to carry along the ten circles inclosed by it, in its daily rotation from east to west, while each planet traverses its ascribed path from west to east about the earth; the twelfth and last circle, *a*, Ptolemy indicated by the name of Empyræum, or the abode of spirits and the blessed. This Ptolemaic system explains the heavenly appearances only imperfectly, provides in no way for the varying distances of the planets, and is, on the whole, very unnatural; it endured, however, with little change until the time of Copernicus.

Certain of the Egyptian astronomers easily perceived that the arrangement of the orbits of Venus and Mercury, according to Ptolemy, could not be the true one, since it could not explain the superior conjunctions of these two planets. They, therefore, allowed the moon, and then the sun, to revolve (*pl.* 7, *fig.* 2) round the earth, but supposed Venus and Mercury to revolve round the sun in minor orbits, accompanying it in its revolution round the earth. Mars, Jupiter, and Saturn moved in great circles about the earth, as in the Ptolemaic system. This system, termed the *Egyptian*, is as false as the Ptolemaic, and could not be maintained so long in authority. It was reserved for the great Copernicus (1472—1543) to teach the world the true theory of the arrangement of the primary and secondary planets, afterwards confirmed by the laws of Kepler, and the discovery by Newton of the law of universal gravitation. According to this theory the sun ☉ is a fixed star, occupying the centre of as many circular orbits as there are primary planets. These latter occur in the following order from the sun; Mercury ☿, Venus ♀, Earth ♁, Mars ♂, Jupiter ♃, Saturn ♄; the Moon ☽, a secondary planet, revolves about the earth, and with it around the sun. All these motions take place in the direction from west to east (shown by the direction of the arrows, *fig.* 5).

Tycho de Brahe, who lived in the second half of the sixteenth century, certainly recognised the correctness of the Copernican system at an early period, but his ambitious vanity, and perhaps still more his religious prejudices, urged him to oppose it. In Tycho's opinion the earth could not move around the sun, because the Bible would be thereby falsified. He preferred to represent the earth (*fig.* 3), like the earlier theorists, as placed immovably in the centre of the universe, the moon revolving round it first, and then the sun; around which latter the other planets, Mercury, Venus, Mars, Jupiter, and Saturn, revolve as their centre. This system of Tycho, however, could not longer maintain any stand when the true Copernican system had been discovered. The Copernican system received a very essential confirmation by Kepler, who showed that the planets revolve in orbits that are ellipses, but which differ very little from circles, the sun being situated in one focus common to all (*pl.* 10, *fig.* 2). This is also approximately exhibited in *pl.* 7, *fig.* 5, by the eccentric position of the circular planetary orbits.

Since the invention of the telescope, the following primary and secondary planets have been discovered as members of our solar system; the four

moons of Jupiter, the ring and seven satellites of Saturn, the planet Uranus ♅ (March 13, 1781, by Herschel), his six moons also by Herschel, Ceres ⚳ (Jan. 1, 1801, by Piazzi), Pallas ⚴ (March 28, 1802, by Olbers), Juno ⚵ (Sept. 1, 1804, by Harding), Vesta ⚶ (also by Olbers, March 29, 1807), Astræa ⚸ (Dec. 8, 1845, by Henke), Neptune ♆, his ring and moon (Sept. 23, 1846, by Galle), and the planet provisionally called Iris (July 1, 1847, by Henke). The orbits of all these planets and moons, except Astræa, Iris, and Neptune, are represented on *pl.* 7, *fig.* 5, upon which are represented also the orbits of Halley's Comet 1759, 1835, and of the great comet of 1811, as well as that of Encke. The outer circle of the figure represents the ecliptic with its division into the 12 signs, and on it are indicated by corresponding signs, in what parts to look for the following points:—the ascending node, ☊, of the great comet of 1811; the aphelion of Mars; the aphelion of Jupiter; the descending node, ☋, of Mars; the aphelion of Juno; the perihelion of Vesta; the descending nodes of Mars and Venus; the aphelion of Saturn; the descending node of Jupiter; the aphelion of the Earth; the descending node of Saturn; the aphelion of Pallas and Venus; the descending node of the Comet of 1811, and the aphelion of Ceres. In addition to these are given the proportional diameters for the Sun, Jupiter, Saturn, and Uranus.

24. Since the planets move slower in their orbits as their distance from the sun is greater, *fig.* 6, *pl.* 7, is intended to exhibit the relative velocity of these motions. When Mercury, the planet nearest to the sun, has completed an entire revolution in 360°, Venus in the same time describes an arc of 141° 22′, the Earth an arc of 86° 44′, &c. The proportionate velocities of the recently discovered planet Astræa (between Vesta and Juno) and Neptune (almost twice the distance of Uranus from the sun) could not well be represented in the figure. Astræa, if introduced into the preceding comparison, would describe an arc of about 21°, and Neptune one of about 20′. From the measurement of these various axes, it results, that Venus moves 2½, the Earth 4, Mars 8 times slower than Mercury. *Fig.* 7 represents the inclinations of all the planetary orbits (except those of Astræa, Iris, and Neptune) to the plane of the ecliptic or the earth's orbit.

25. We shall now present a tabular view of the most important elements of our planetary system, principally with regard to those points which could not be represented on *pl.* 7, without affecting the distinctness of the figures. The estimates are given in English geographical miles, according to the most recent observations and calculations. The different values ascribed to Neptune may possibly require rectification whenever his elements are better known than they can be now.

Distance, Period of Revolution, and Eccentricity of the Planets.

Planets.	Mean distance from the Sun.	Eccentricity.	Sidereal period in mean solar days and Julian years.
Mercury .	32,000,000	6,580,000	87*d* 23*h* 15′ 46″
Venus . .	65,392,000	412,000	224 16 49 7
Earth . .	82,664,000	1,388,000	365 5 9 10 7‴
Mars . .	125,956,000	11,740,000	1*y* 321 17 30 41
Vesta . .	195,212,000	17,296,000	3 229 17 38 0
Astræa . .	212,864,000	18,716,000	4 49 6 8 50
Juno . .	220,672,000	56,400,000	4 132 1 36 0
Ceres . .	229,052,000	17,564,000	4 223 17 38 0
Pallas . .	229,192,000	55,468,000	4 225 7 19 0
Jupiter . .	430,084,000	20,732,000	11 314 20 2 7
Saturn . .	788,516,000	44,232,000	29 166 23 16 32
Uranus . .	1,185,692,000	73,892,000	84 5′ 19 41 36
Neptune .	2,900,584,000	25,524,000	167½

Rotation, Light, Gravitation, Density, &c., of Planets.

Planets.	Mass. The Sun = 1.	Density. Earth = 1.	Gravitation. Earth = 1.	Light & Warmth. Earth = 1.	Rotation in Mean Solar Time.
Mercury .	1.2025810	2.94	1.15	6.67	1*d* 0*h* 5′
Venus . .	1.401847	0.92	0.91	1.91	0 23 21
Earth . .	1.354936	1.00	1.00	1.00	0 23 56.1
Mars . .	1.2680337	0.96	0.50	0.43	1 0 37.3
Jupiter. .	1.1054	0.24	2.69	0.037	0 9 55.5
Saturn . .	1.3500	0.14	1.26	0.011	0 10 29.3
Uranus. .	1.17918	0.24	1.05	0.003	

Surfaces and Volumes of the Planets in Geographical Miles.

Planets,	Surfaces in Square Miles.	Volumes in Thousands of Cubic Miles.
Mercury.	22,272,000	10,210,816
Venus	144,048,000	163,373,248
Earth, ...	148,512,000	170,180,672
Mars, ...	40,096,000	23,825,280
Vesta, ...	148,500	832
Juno, ...	4,448,000	850,880
Ceres, ...	5,936,000	1,361,472
Pallas, ...	10,400,000	2,893,056
Jupiter, ...	18,710,496,000	230,635,198,720
Saturn, ...	12,088,880,000	124,082,652,800
Uranus, ...	2,802,416,000	13,954,799,360
Sun, ...	1,865,312,000,000	239,460,953,408,000
Moon, ...	10,350,400	3,024,812

Velocity and Fall of the Planetary Orbits; their position with respect to the Sun's Equator.

Planets.	Mean Velocity in a Second.	Fall towards the Sun in a Second.	Right Ascension of the Ascending Node of the Orbit.
Mercury . . .	26.8 Eng miles.	8.46	316° 51′
Venus . . .	19.6	2.42	242 45′
Earth	16.4	1.27	248 0′
Mars	13.6	0.55	254 21′
Vesta	10.8	0.20	180 33′
Juno	10.4	0.20	197 3′
Ceres	10.0	0.20	208 43′
Pallas	10.0	0.20	182 19
Jupiter . . .	6.8	0.047	242 5′
Saturn . . .	5.2	0.014	231 12′
Uranus . . .	4.0	0.003	247 30′
Neptune . . .	2.8		

Inclination and Motion of the Planetary Orbits.

Planets	Inclination of the Orbit to the Sun's Equator.	Arc of the Retrograde Motion.		Duration of the Retrograde Motion.
Mercury . . .	2° 54′	8° 33′	16° 18′	20 and 24 days.
Venus. . . .	4 9	15 20	16 31	41 " 43 "
Earth	7 30			
Mars	5 50	11 8	19 30	62 " 81 "
Vesta	4 28			
Juno	16 28			
Ceres	3 43			
Pallas . . .	37 8			
Jupiter . . .	6 24	10 0		119 "
Saturn . . .	5 57	6 48		137 "
Uranus . . .	6 44	3 36		151 "

The most important items respecting the moons of Jupiter, Saturn, and Uranus, will be found further on, principally in section 33. Sections 30 and 31 will contain the principal points in the history of our moon.

Annual Revolution of the Earth around the Sun, and Various Phenomena resulting from this Revolution.

26. The central figure on *pl.* 8 is intended to exhibit clearly, with many other phenomena, the annual revolution of the earth about the sun; nevertheless, for the better knowledge of the whole subject, it will be necessary to premise a few general observations. It is, in the first place, evident that bodies cannot themselves change their condition, and that thus a body once set in motion can never stop—that it will continue to move in the same direction and with the same velocity as when it set out, unless some other external force changes its direction or velocity. This peculiarity of

bodies is called inertia. It is, moreover, evident, by reference to what is said, sec. 46, of the parallelogram of forces, that if the paths of the planets, and consequently of the earth, also be ellipses about the sun, two forces must combine to their production. The one is the *attractive force* of the sun, varying with the distances; the other a continuous *tangential force*, originating in an impulse. *Pl.* 10, *fig.* 2, will show how an elliptical orbit for each planet is produced by the co-operation of these two forces. We have to remark, finally, that gravitation communicates to all freely falling bodies a tendency towards the centre of the earth.

We will now direct our attention to the orbit of the earth, with the help of the figure in *pl.* 8, representing its motions. By measuring the distances of the earth from the sun, at different times of the year, the shape of its orbit has been ascertained. These distances, as they were unequal, could not, of course, be semi-diameters of a circle, but they corresponded, taken together, to the radii vectores of an ellipse (*pl.* 10, *fig.* 2). The mean distance of the earth from the sun, is about 95,103,000 (statute) miles; it moves in its orbit at the average rate of $16\frac{4}{10}$ (Eng. geog.) miles in a second; the eccentricity of its orbit amounts to 0,016,784; the least or perihelion distance from the sun, to 81,276,000 (Eng. geog.) miles, or 33,917,997 hours; while the greatest or aphelion distance is 84,052,000 (Eng. geog.) miles, or 35,085,379 hours. The straight line connecting the perihelion and aphelion, passing through the centre of the sun, is called the line of *apsides*. The inclination of the earth's orbit to its equator, or the so-called *obliquity of the ecliptic*, amounts to 23° 27′. The velocity of the earth is greatest at the perihelion and least at the aphelion. It is further to be observed, that the mean distance of the earth from the sun is equal to half the major axis of the earth's orbit, and the line of apsides is itself the major axis. There are four noteworthy points in the earth's orbit; they are those which mark the beginning of the four seasons. Two of these points are called the *solstices*—they mark the beginning of winter and summer. The straight line (*pl.* 8) uniting them, passing through the centre of the sun, is called the *solstitial colure*. The two other points are the *equinoxes*, vernal and autumnal, marking the commencement of spring and autumn. The straight line connecting these points, passing through the centre of the sun, is the *equinoctial colure*. It still remains to observe, that the axis of the earth being always parallel to the axis of the heavens, may also be conceived to coincide with it; for, in consequence of the great distance of the fixed stars from our sun, the diameter of the earth's orbit (of more than 190,000,000 [statute] miles), as well as the whole orbit itself, would be seen as a mere point at the stars.

The representation on *pl.* 8, shows the position of the earth on the first day of each of the twelve months of the year, the solar distances corresponding to these twelve positions, and the shape of the earth's orbit. The horizontal projection has been chosen, in order to represent to the eye the increase and diminution of days, and the variation of illumination about the pole of the earth. The deeper circle surrounding the pole at a short distance, is intended to represent the parallel of latitude of Paris, or the hour

circle of that place divided into twenty-four hours. Although at the end of December the earth is nearest the sun, yet at that time in the northern hemisphere, the heat is less than at any other. The reason of this lies in the fact of the short days and long nights, as well as that the sun's rays fall very obliquely on the earth, traversing a longer path through the atmosphere, and consequently losing much of their heating power. At the beginning of July, on the contrary, although then the earth is at its greatest distance, the temperature of the northern hemisphere is greatest, on account of the long days and short nights, and the great altitude of the sun at noon. This, of course, depends upon the declination of the sun north or south from the equator. This declination of the sun for the first day of every month, is given in *pl.* 8. The great inner circle contains the division of the year into days and months, and enables us, by drawing a straight line to any point of this circle, to find the situation of the earth on the day corresponding to the point. The external circle, on the contrary, is divided into twelve equal arcs, of which each one answers to a *sign* (30 degrees) of the ecliptic. It must not be forgotten, however, that owing to the precession of the equinoxes, these signs no longer correspond to the constellations of the same name, so that now the sign Pisces corresponds to the constellation Aries, the sign Aries to the constellation Taurus, &c. It is further evident from an inspection of the *plate.* that if the earth at the beginning of spring, summer, autumn, and winter, should be in the signs Aries, Cancer, Libra, and Capricornus respectively, then the sun, as being always directly opposite in the ecliptic, will be in the signs Libra, Capricornus, Aries, and Cancer.

By properly combining the preceding with sections 27, 28, which are devoted principally to an explanation of the theory of the seasons, and particularly of the daily and yearly motion of the sun, it will not be difficult to obtain a perfect idea of all the phenomena occurring in the course of a year, over the whole surface of the earth. On account of the great importance of this subject, it may be remarked further, that the changes of days and nights, as also of the seasons, may be very easily represented by means of a *Tellurium*, or by means of a terrestrial globe, with a little simple additional mechanism.

The inner space of *pl.* 8, is employed to represent the orbits of the two inferior planets, Mercury and Venus, in their proportional size, shape, and eccentricity. The accompanying figures are readily intelligible without further explanation.

27. The sun is stationary! It is incredible that so enormous a body as the sun should have three different motions at the same time. Accurate observations have shown that the earth moves about its axis from west to east, once every day, by means of which the daily apparent motion of the heavens, as well as of the sun, from east to west is produced. It is furthermore only apparently, not really, that the sun in the course of a year moves around the earth from west to east in an ellipse termed the *ecliptic* (*pl.* 9, *fig.* 3, LCD), making an angle with the equator of 23° 27′. This inclination, termed the *obliquity of the ecliptic*, combined with the revolution of the earth, explains the apparent motion of the sun, both towards the north and

towards the south. If, for instance, we suppose the sun on June 21st to have reached the point L, it is evident that while the earth rotates about her axis, *ax*, from west to east, or in the direction from Q to U, it will seem as if the sun in the same time, but from east to west, had described the parallel circle, VOLV (or the tropic of Cancer), about the earth; wher the sun is at R, he will appear to describe the equator CRFC; and on December 21st, the tropic of Capricorn or the circle DHMD. The planes of the equator and tropics intersect the earth in circles, which are respectively the terrestrial equator and the terrestrial tropics. It is further to be observed that the poles, N, K, of the ecliptic, during the apparent daily rotation of the heavens, describe two small circles, of which the northern, AN, is called the *arctic*, the southern, BK, the *antarctic*. The polar circles of the earth corresponding to these are *u*, *y*, and *k*, *b*.

The rotation of the earth on its axis, and the inclination of the ecliptic to the equator, explain without any difficulty the inequality of days and nights, and the succession of the seasons. For when the sun on the 21st June traverses the tropic of Cancer, he remains much longer above the horizon *zz* than when describing the tropic of Capricorn on Dec. 21. In this latter case we readily perceive that the sun remains much longer below the horizon, and that consequently the nights are much longer than on the 21st of June. It is further evident, that about the 20th of March and 23d of September, when the sun is on the equator, an equality of days and nights must take place. *Figs.* 1 and 3, *pl.* 9, also show that during the six months that the sun is north of the equator, spring and summer must take place in the northern hemisphere, autumn and winter in the southern; but during the six months that this luminary is south of the equator the case must be reversed, spring and summer now happening in the southern hemisphere, autumn and winter in the northern.

28. All that has hitherto been said with regard to phenomena occurring in connexion with the earth, can only be explained by the assumption of a rotatory motion of the earth about an axis at the same time with a revolution about the sun in an elliptical orbit (*pl.* 9, *fig.* 1). The inequality of the seasons is a necessary consequence of the elliptic motion of the earth, and of the inclination of its axis of rotation to the plane of the ecliptic. If, for instance, the axis of rotation were perpendicular to the plane of the ecliptic, then there would be no change of seasons, but rather a single continuous torrid, temperate, or frigid zone. In this case also the planes of the equator and ecliptic would coincide, and as the sun would remain constantly in this plane, the days and nights would be equal the whole year through, and the poles of the earth be illuminated by only half the sun's disk. The equatorial regions would have a burning summer continually, the temperate zones would have an eternal spring, and the polar lands would experience without intermission intense cold, in which ice would never melt. But the axis of the earth, ever parallel to itself, is inclined to the plane of the ecliptic 66° 33′, and thence follows,—1st, a progressive difference in the length of the days and nights for all points of the earth's surface from the equator to the poles, and from the first day of the year to the last; 2dly, an increase and diminu-

tion of temperature for the northern and southern hemispheres, in proportion as these are turned more or less to the sun. *Pl.* 9, *fig.* 1, shows that the earth (revolving in the direction of the arrows), wherever in her orbit she may happen to be, always has her axis constantly parallel to itself and at the same angle of inclination to the plane of her orbit. The earth is found at A, on Dec. 21, in the beginning of winter, the shortest day of the year for our northern hemisphere. The sun is then at his greatest distance south, describes the tropic of Capricorn, and at noon stands in the zenith to all inhabitants of the earth whose latitude is 23° 27′ south. The north pole, nevertheless, lies in the middle of its six months' night. The boundary of the earth's shadow will fall in the north polar circle, whose inhabitants will then have a night of 24 hours. On the other hand, this will be summer to the southern hemisphere, and its inhabitants will have the longest days. This point, A (*fig.* 1), of the earth's orbit is the winter solstice; the earth, which now, seen from the sun, stands in 0° of Cancer, will traverse the part AB of its orbit in 89 days, from Dec. 21 to March 20, thus marking the duration of the winter.

B is the position of the earth on the first day of spring (autumn for the southern hemisphere): the sun then describes the equator (see the direction of the equinoctial line), and as the shaded portion of the earth divides the parallel circles into two equal parts, the days and nights will at this time be equal all over the world. At the north pole the long day of six months is just commencing. The earth, standing in 0° of Libra, now traverses the part BC of its path in 93 days, from March 20th to June 21, marking the duration of spring.

C is the position of the earth on June 21, the first day of summer (of winter in the southern hemisphere); the sun then describes the tropic of Cancer, and the north pole lies in the middle of its day of six months. The inhabitants of the north polar, or arctic circle, see the sun for 24 hours, and all other dwellers on the northern hemisphere have longer days than nights. The south pole lies in the middle of its night of six months, and the inhabitants of the southern hemisphere have longer nights than days. C is the summer solstice, and the summer lasts 94 days, that is, the time from June 21st to Sept. 23, during which the earth passes from C to D. The earth itself, on the 21st June, as seen from the sun, stands in 0° of Capricornus.

Finally, on the 23d Sept., the first day of autumn (spring for the southern hemisphere), the earth is at D, the sun standing again in the equator, the days and nights are again equal all over the earth. The sun now becomes invisible to the north pole, and visible to the south pole, the autumnal equinox occurring on Sept. 23d, the vernal on March 20. Autumn lasts 89 days, that is, the interval from Sept. 23d to Dec. 21, in which time the earth traverses the distance DA of its orbit.

From the preceding explanation it is evident that the four seasons are not of equal duration, for spring and summer together embrace 187 days, while autumn and winter last only for 178 days. There is thus a difference of nine days between the times occupied by the earth in traversing BC, CD, and DA, AB. This difference of nine days is a consequence partly of the

eccentricity of the earth's orbit, partly of the varying velocity with which the earth moves around the sun.

The Transit of Mercury and Venus across the Disk of the Sun.

29. When the inferior planets, Mercury and Venus, during their revolution around the sun, come into inferior conjunction, and at the same time into or not far from the imaginary straight line drawn through the centres of the sun and earth, they will, if examined through a telescope, be seen as dark spots passing over the sun's disk (*pl.* 14, *fig.* 55). These *transits* of Mercury and Venus belong to the rarer celestial phenomena, since they evidently can only take place when inferior conjunction occurs near one of the nodes of their orbits. It is plain that with regard to the origin and progress of these transits, the conditions are precisely the same as in eclipses of the sun, which latter might be called with equal propriety, transits of the moon over the sun's disk. Astronomy teaches that Venus at her inferior conjunction must be within 1° 49′ of one of her nodes, and Mercury within 3° 28′, for a transit to occur to any observer on the earth's surface. These two limits, then, determine the periods of these occurrences, which for Venus are 8 and 113½ years, and for Mercury 6, 7, 10, and 13 years. Thus, transits of Venus happened on June 5, 1761, and June 3, 1769; the next will take place December 9, 1874, and December 6, 1882, June 7, 2004, and June 5, 2012. *Pl.* 9, *fig.* 6, exhibits the 13 transits of Mercury during the present century, with its direction each time over the sun's disk. It is to be remembered that Mercury as well as Venus will enter on the left (eastern) limb of the sun, and emerge on the right (western) limb, for the reason that at the time of their inferior conjunction these planets are retrograding. The reason of the transits of Venus occurring in the beginning of June and December, and those of Mercury only at the beginning of May and November, lies in the fact, that at these times the earth is in the line of nodes of each planet respectively. On account of the small apparent diameters of Venus and Mercury, these phenomena could not be detected before the discovery of the telescope. The first transit of Mercury was observed by Gassendi at Paris, November 7, 1631; the first transit of Venus by Horrox, at Hoole, in England, December, 1639.

The observation of the transit of Venus is to the astronomer of vast importance, as it is almost the only certain way of obtaining the sun's parallax, and hence of finding the mean distance of the sun from the earth. Halley first recognised this fact, and recommended these transits to the observations of astronomers. His suggestion was followed out when the next transits occurred in 1761 and 1769, and at these times observations were made in many places. The transit of 1769 was observed in the South Seas, in California, as also in the northern regions of Asia. Venus at the time of her inferior conjunction is very near the earth, and consequently seen from different places on the earth's surface, will be referred to very different points on the sun's disk, so that first of all the parallax of both Venus and

the sun can be obtained. According to Encke, who has fully and most accurately carried out the calculation, the mean horizontal parallax of the sun at the equator amounts to $8\frac{5}{1}\frac{7}{0}\frac{7}{0}\frac{6}{0}$ seconds, and consequently the mean distance of the earth from the sun to 95,103,000 (English) miles. That the transits of Mercury are not available in determining the sun's parallax, is readily intelligible, when we know that the parallax of Mercury at its inferior conjunction is not very different from that of the sun, while the parallax of Venus at inferior conjunction is almost four times as great as that of the sun.

Pl. 9, *figs.* 7 and 8, represents the individual phenomena of the transits of Mercury for the whole earth, as they occurred May 4, 1786. The obscure portions in *figs.* 7 and 8 cover those regions in which the transit was visible, the bright portions answer to the countries in which it was invisible. Those places lying in the boundary of the obscure and light parts, observed, as indicated in the figures, either an entrance or emersion at sunrise only, or an entrance or emersion at sunset only.

Additional Remarks on the Course of the Moon.

30. We have already said all that is essential with respect to the origin of the moon's phases, the inclination of the moon's orbit to the ecliptic, the retrograde motion of the moon's nodes, as also the causes of solar and lunar eclipses. There still remain a few additional considerations respecting the moon's course. The principal figure on *pl.* 10, *fig.* 5, contains the phases of the moon, or the various aspects under which she presents herself to us. The earth being in the centre of the external circle, the moon's orbit is so placed, with reference to this circle, as readily to exhibit its eccentricity. The moon revolves in this orbit from west to east around the earth, and the figure represents her in her proper proportion to the earth and in the eight principal points of her course. The sun may be supposed to be stationed at a distance to the right of the earth in *pl.* 10, exceeding 410 times that of the moon from the earth. In order to exhibit the phases of the moon in their fullest conditions, they are represented within the moon's orbit in much larger proportion. The orbit of the moon is properly an ellipse, the earth standing in one of the foci. Its eccentricity amounts to 0.0548442; the greatest distance of the moon from the earth (that is at time of the apogee), to 63.842 semi-diameters of the earth, and the least, or that at time of perigee, to 55.916 semi-diameters. Both perigee and apogee retrograde from evening to morning about 40° 42′ annually. The moon appears to revolve in 24 hours from east to west around the earth, which, with the apparent daily motion of the heavens, is produced by the rotation of the earth on her axis. Again, the moon, as full moon during the nights of summer, appears to describe a very small arc, and during the nights of winter a very large arc above the horizon, which is explained in the following manner: Let us suppose the night to be that of the winter solstice (*pl.* 9, *fig.* 1), on December 21, consequently the longest night in the year. Let now the

earth (*pl.* 10, *fig.* 4) be opposite the sun, situated in the tropic of Capricorn, which it describes on this day, and the moon, as full moon at M, in the tropic of Cancer, which she describes; our horizon, HR, shows that the diurnal arc of the sun is very small, while the moon traverses by night a very large arc. The contrary of this must take place on the night of the summer solstice, June 21, the shortest night of the year. Should the moon, as full moon in spring and autumn, stand in the equinoxes as the sun, she would then be as long above as below the horizon.

31. If we suppose the moon to be at L′ (*pl.* 10, *fig.* 3), in conjunction or between the earth and sun, then the centres of these three bodies will be in the straight line RE. While the moon is completing a revolution around the earth, moving daily about 13° 10′ 35″, the earth will have passed forward over a certain part of her orbit, about to *t*. The moon will then be at *n*, in a direction, *xz*, which is parallel to the former, RE. The moon has consequently a periodical or tropical revolution completed within 27 days, 7 hours, 43 minutes, $4\frac{7}{10}$ seconds. For the moon to return to conjunction, however, that is, again to become new moon, it must in addition traverse the arc *n*L, equal to the arc T*t* or R*m*, described by the earth in its orbit, which arc amounts to about 27°. To accomplish this the moon requires somewhat more than two days; she consequently returns to conjunction in 29 days, 12 hours, 14 minutes, and 3 seconds. This period is known as the lunar month (in its proper sense), and the revolution itself (from conjunction to conjunction) is the synodic revolution, or simply the lunation, which may also be counted from one full moon to another. *Pl.* 10, *fig.* 10, shows that the course of the moon projected on the plane of the earth's orbit, must form a kind of serpentine. The moon has yet to pass over the arc *nv* (*fig.* 3), to come back to the same fixed star; this return, accomplished in 27 days, 7 hours, 43 minutes, and 12 seconds, is called the *sidereal revolution* of the moon. Finally, the revolution of the moon, with respect to the nodes of its orbit, occupies 27 days, 5 hours, 5 minutes, and 36 seconds.

The moon revolving about our earth is forced to accompany her in her course round the sun, so that the path traversed by the moon in space is properly an epicycloid. This compound motion of the moon is, consequently, the source of the various phases represented in *fig.* 5, as already explained in sections 7 and 29. *Pl.* 10, *fig.* 5, shows, in addition, the first, second, third, and fourth octants, as also that the moon, when full, is in opposition to, and when new, in conjunction with the sun. The inclination of the moon's orbit to the earth's equator is very variable, ranging in 19 years from 18° 19′ to 28° 36′. The inclination of the moon's equator to the ecliptic (1° 28′ 25″) never varies. The time of the rotation of the moon about her axis corresponds precisely with that of her mean revolution around the earth, consequently equal to 27 days, 7 hours, 43 minutes, and 12 seconds. Hence the moon always turns the same side to us, and the opposite side is constantly concealed, except the small part of it revealed by *libration*. For this reason the conclusion was early formed, though too hastily, that the moon had no rotation.

The Primary Causes of the Elliptical Orbits of the Planets; Kepler's Laws.

32. In the explanation of the yearly course of the earth about the sun (by means of the figure on *pl.* 8), it was mentioned that the paths of the planets, and consequently those of the earth and moon, are ellipses, which are produced by the co-operation of two special forces. How that takes place will be explained hereafter. Let us suppose that any body (as ♏, *pl.* 10, *fig.* 2) once set in motion is impelled by two forces; let the line ♏P represent the direction and intensity of the one force, the line ♏V the direction and intensity of the other. It is evident that the body ♏ will not move towards S, the sun alone, nor towards *x* alone. It must rather (see what is said, section 26, about compound motion) follow the direction ♏*o*, and pass to the point *t*; the force represented by ♏P is the attractive force of the sun at S, and the force represented by ♏V, is the tangential force produced by an impulse. As the ever-varying central force, namely the attraction of the sun, is constantly acting upon this tangential force, this must also vary. The curvature ♏ ♎, ♏ ♌, of a planet's orbit, produced by the co-operation of these two forces in the first, and in all following moments, must manifestly depend upon their relative proportion. The central force again depends upon the distance of the planet from the sun. Should the original velocity of the planet in the first second be exactly equal to the planet's fall towards the sun in the same second, then the ratio will be 1 : 1, and the orbit will be a circle. It is perfectly plain, however, and much more probable, that the original velocity may have been a little greater or less than what would be necessary to the production of a circular orbit. Then the planet would move in an ellipse (*pl.* 10, *fig.* 2), in which the point ♉, where the planet started, would be the perihelion if the projectile force had been the greatest, for it would recede from the sun from the very beginning of its motion. But if the planet had started in the point ♋, the projectile force must have been the lesser of the two, and the point ♋ would be the aphelion. The higher mechanics shows that ellipses arise when, beginning at the perihelion, the original velocity amounts to from $51\frac{96}{100}$ to $73\frac{36}{100}$ English geographical miles in a second, and that ellipses likewise arise when, beginning in the aphelion, the original velocity amounts to from $\frac{4}{100}$ to $51\frac{88}{100}$ geographical miles in a second. It has actually been found that the planets (and their moons), whether starting in their perihelion or aphelion, must have had initial velocities falling within the above limits, and consequently must describe elliptic orbits.

If the tangential force operate on the point ♏, in the direction V♏, and the attractive force of the sun in the direction P♏, the point ♏ will move in the direction ♏ ♎ to ♎. At ♎ the tangential force operates in the direction B♎, and the central force in the direction *p*♎, therefore the point ♎ now moves in the direction ♎♍ to ♍. At ♍ the tangential force acts afresh in the direction D♍, and the central force in the direction *k*♍, consequently the point ♍ now moves in the direction ♍ ♌ to ♌, &c. It is hence evident that the planet must describe an ellipse, not, however, the broken

line ♏♎, ♏♌. For we may suppose the parallelogram of forces to be constructed anew every successive moment, and consequently infinitely small, so that instead of the broken line, a continually curved one, namely an ellipse, will be produced, since both forces, the central and tangential, operate incessantly upon the planet. It is only for the more intelligible illustration of the subject that the single parallelograms in *fig.* 2 are represented on so large a scale; the eccentricity, CS, is, for the same reason, assumed tolerably great, as the real eccentricity of the planetary orbits is much less.

The proposition that *the planets describe ellipses, the centre of the sun being in one of their foci*, is the first of the three celebrated laws of Kepler, upon which the whole theory of the planetary motions depends. The second law (discovered, however, first) is, that *any two areas (sectors), SQq and SQ'q', described by the radii vectores, SQ* and *Sq, SQ'* and *Sq', are proportional to the times* (*pl.* 6, *fig.* 4). This law may also be expressed in this manner: The different velocities of a planet are as the squares of its different distances from the sun. Suppose the planet to describe the distances Qq, and $Q'q'$ of its orbit in equal times, then the elliptical sectors, SQq and $SQ'q'$, will have equivalent areas. Hence it follows, that if the areas of the sectors at the perihelion B and at the aphelion A are to be equivalent, the arc described by the planet at the perihelion must be greater than that described in equal time at the aphelion. Thus the planet must move with the greatest velocity at the perihelion, and the least at the aphelion, and these two different velocities are as the squares of the distances SA and SB. In general, the velocity of a planet's motion must be greater as it approaches the sun, and less as it recedes from it.

The first law of Kepler expresses the character of the curve described by the planets; the second, the varying velocities of the planetary motion; while the third law is a bond of union connecting the different planets together. This third law is expressed as follows: *the squares of the times of revolution of two planets are as the cubes of their mean distances from the sun.* The great value of this law consists in its presenting a geometrical proportion, so that knowing three of the four elements, the mean distances from the sun, and the periods of revolution, the fourth can always be obtained. In conclusion, the laws of Kepler are true laws of nature, since Newton has demonstrated that they are only consequences of that single and supreme law discovered by him—*the law of universal gravitation.*

The Moons of Jupiter, Saturn, and Uranus.

33. The planet Jupiter is accompanied by four moons in his journey of $11\frac{1}{2}$ years around the sun. Immediately after the discovery of the telescope, Simon Marius (at Ansbach), in November, 1609, observed four small stars very near to Jupiter, which, almost always in a straight line with him, appeared sometimes to the right, sometimes to the left, never separating

far from him. Marius observed them carefully, and in March, 1610, was convinced that those four small stars were moons of Jupiter. Galileo observed them for the first time on January 10th, 1610.

Indicating the satellites of Jupiter by I., II., III., IV., their mean distances from the centre of Jupiter are as follows:—232,000 (English) geographical miles for I.; 372,000 for II.; 592,000 for III.; and 1,040,000 for IV. The eccentricities of their orbits (*pl.* 10, *fig.* 6) are inconsiderable, as also their inclinations. The sidereal period of I. is 1 day, 18 hours, 28 minutes; of II., 3 days, 13 hours, 14 minutes; of III., 7 days, 3 hours, 43 minutes; and of IV., 16 days, 16 hours, 32 minutes. These are uncommonly short, and consequently eclipses of Jupiter's moons occur with remarkable frequency. We often see one or another moon vanish suddenly and re-appear on the eastern side after the lapse of some hours. A tolerably attentive examination soon shows that such an eclipse of the moon is produced by the shadow of the primary. This also shows incontestably that Jupiter and his four moons are opake bodies, deriving all their light from the sun.

By the assistance of a good telescope, it will frequently be observed that these moons enter Jupiter's disk on the eastern border, moving towards the western border, accompanied by circular dark spots, going in the same direction and with the same velocity. These spots are evidently nothing else than the shadows of the moons cast from them upon the surface of Jupiter. These phenomena are consequently eclipses of the sun to Jupiter, produced by his moons. The maximum duration of the eclipses amounts for satellite I., to 2 hours, 16 minutes; for II., to 2 hours, 52 minutes; for III., to 3 hours, 34 minutes; and for IV., to 4 hours, 45 minutes. In one year of Jupiter, that is in almost 12 of our years, 4,400 eclipses of the moons, and as many of the sun, may be observed. The beginning and ending of the same eclipse of I. and II. are never both seen, as before the opposition to Jupiter only the beginning, and after it, only the ending are observed. On the other hand, both beginning and ending in III. and IV. may be perceived. With respect to eclipses of the sun, it is to be remarked that at the time of visible beginning, the shadows follow the satellites, and precede them at the time of ending. In conclusion, one moon of Jupiter may sometimes, though rarely, eclipse another.

Observations of the so frequently occurring eclipses of Jupiter's satellites offer an exceedingly ready means of determining geographical longitude. Unfortunately, the moment of such an eclipse, just as in the case of an eclipse of our moon, will be observed very differently at different places, owing to the unequal illumination and magnifying power of telescopes, and the different acuteness of sight of the several observers. It was the observation of the eclipses of Jupiter's satellites that led the Danish astronomer, Olaus Römer (in the latter half of the seventeenth century), to the discovery of the velocity of light.

When Jupiter is at his mean distance from the earth, the diameters of his moons appear to us respectively at angles of 1″.02, 0″.91, 1″.49, 1″.27. Hence the apparent diameters of his moons to Jupiter will be 31′ 11″,

17′ 35″, 18′ 0″, and 8′ 54″. The true diameters are for I., 2,120; for II., 1,880; for III., 3,120; and for IV., 2,640 English geographical miles; their densities are $\frac{1}{5}$, $\frac{2}{5}$, $\frac{3}{10}$, and $\frac{1}{4}$ that of the earth.

34. The planet *Saturn*, on his 30 years' journey around the sun, is accompanied by seven moons, revolving round him from west to east. Huyghens discovered one of these moons, namely, the sixth, March 25, 1655. Cassini found the seventh and most distant on October 25, 1671; the fifth on December 13, 1672; as also in March, 1684, the third and fourth. One hundred years after, August 28 and Sept. 17, 1789, Herschel discovered the two satellites nearest the planet. The orbits of the six inner moons (*pl.* 10, *fig.* 7) are nearly circular, and lie almost entirely in the plane of Saturn's ring; the orbit of the seventh, however, lies nearly in the plane of the ecliptic. Their periods of revolution are 0 days, 22 hours, 38 minutes; 1 day, 8 hours, 53 minutes; 1 day, 21 hours, 18 minutes; 2 days, 17 hours, 45 minutes; 4 days, 12 hours, 25 minutes; 15 days, 22 hours, 41 minutes; and 79 days, 7 hours, 55 minutes. Their mean distances from Saturn amount, in geographical miles, to 76,680, 99,640, 163,880, 211,680, 295,480, 642,840, 2,098,744. With regard to the true magnitudes, masses, and densities of the satellites of Saturn, nothing satisfactory is known, as these moons are among the smallest and most remote objects of the heavens. Schröter estimated the true diameter of the fifth and sixth satellites at 1,040 and 2,720 geographical miles. It is only since 1830 that the sixth moon has received a more accurate determination by Bessel.

The first and second moons had only been seen by their discoverer Herschel, until in 1836 Camont found the second, and in June 27, 1838, the astronomers at Rome were enabled to observe the first. The seventh or outermost moon revolves about Saturn at the great distance of 2,098,744 geographical miles, and has the remarkable peculiarity of almost entirely vanishing when to the east of Saturn, and of shining brightest in its western elongation. This is probably produced by the fact of its completing a rotation about its axis in the time that it is accomplishing a revolution about Saturn, presenting the same side to the earth when it comes into the same position with respect to its primary—the one side reflecting the sun's light much more completely than the other, consequently the equality of the time of rotation and revolution in the secondary planets appears to apply to these bodies also. The moons of Saturn are sometimes eclipsed, and sometimes produce eclipses of the sun to inhabitants of Saturn; nevertheless, both kinds of eclipses, which always follow closely the time of the disappearance of the ring, occur more rarely than in the case of Jupiter, a consequence of the great inclination of their orbits to that of Saturn (*pl.* 10, *fig.* 7). Yet eclipses of Saturn's moons often occur among themselves, and are also caused by the ring.

35. Uranus, on his 84 years' journey about the sun, is accompanied by six moons (*fig.* 8). Herschel, on January 11, 1787, discovered the second and fourth; on January 18, 1790, the first; on February 9, 1790, the fifth; on February 28, 1794, the sixth; and on March 26, 1794, the third satellite of Uranus. These moons are at the following successive distances from their

primary, expressed in geographical miles, 196,000, 254,000, 296,000, 339,600 680,000, and 1,360,000. Their magnitudes, so difficult to determine, must be very great to make them visible at so immense a distance from the earth. The plane of their orbits is almost perpendicular to that of the orbit of Uranus (*fig.* 8); and it is remarkable that these six moons have the unique motion from north to south. The inclination of the equator of Uranus to its orbit, or the obliquity of his ecliptic, is very nearly a right angle, whence all difference of zones must disappear; while, on the other hand, that of seasons must be very great. When near one pole of Uranus, the sun stands during summer almost immovably in the zenith, and afterwards, for almost a year, describes a very small circle about the zenith; in like manner, the satellites present themselves a very long time in the first and last quarters. New moon and full moon only take place when a pole of Uranus has the sun in its horizon, and at this time alone can eclipses of the sun and moons occur.

In conclusion, it may be remarked that *figs.* 6, 7, and 8, *pl.* 10, represent somewhat in perspective, the systems of the moons of Jupiter, Saturn, and Uranus; and *fig.* 9, the orbit of our moon. The proportional size of the orbits is represented as accurately as the *small size of the scale would allow.*

Estimates of the proportional size of the Planets.

36. To obtain a clear idea of the relative size of the planets (Astræa, Neptune, and Iris excepted) and the sun, we may compare the scale at the bottom of *pl.* 14, representing the sun's radius, with the diameters of the circles representing the planets (*figs* 1 to 11). Taking the diameter of the sun, 2AB, at 770,944 geographical miles, that of the eleven planets in geographical miles, and the ratio of the planets' diameters to that of the sun, will be as follows:—

Figs.	Planets.	True Diameter.	Ratio of Diameters of Planets to Sun's Diameter.
1	Saturn,	62,072	1 : $12\frac{3}{5}$
2	Jupiter,	77,228	1 : 10
3	Uranus,	29,888	1 : $25\frac{4}{5}$
4	Earth,	6,880	1 : $112\frac{1}{10}$
5	Venus,	6,776	1 : $113\frac{3}{5}$
6	Mars,	3,572	1 : $215\frac{4}{5}$
7	Mercury,	2,688	1 : $286\frac{4}{5}$
8	Pallas,	1,800	1 : $428\frac{3}{10}$
9	Ceres,	1,360	1 : $566\frac{9}{10}$
10	Juno,	1,200	1 : $856\frac{2}{5}$
11	Vesta,	200	1 : $3{,}854\frac{7}{10}$

The following table exhibits the Relative Volumes of the Sun and Planets.

Planets.	Actual Volume in Millions of Geographical Miles.	Ratio of True Volumes of the Planets to that of the Sun.
Sun,	14,966,309,588	1 : 1
Jupiter,	15,039,700	1 : 995
Saturn,	7,817,666	1 : 1914
Uranus,	872,175	1 : 17,160
Earth,	$10,636\frac{4}{10}$	1 : 1,407,122
Venus,	$10,210\frac{3}{10}$	1 : 1,465,733
Mars,	1489	1 : 10,052,599
Mercury,	638	1 : 23,458,165
Pallas,	$180\frac{9}{10}$	1 : 82,778,261
Ceres,	85	1 : 176,489,500
Juno,	$53\frac{2}{10}$	1 : 281,321,609
Vesta,	$\frac{4}{77}$	1 : 288,101,459,569

37. *Pl.* 14, *figs.* 12–15, gives the four principal positions of Saturn and his rings, with respect to our earth, as they are perceived during the $29\frac{1}{2}$ years' revolution of Saturn about the sun. *Fig.* 12 gives a view of Saturn and his rings at the time this planet is situated in the sign of Cancer (♋); *fig.* 13 represents them when—$14\frac{3}{4}$ years later—Saturn is found in the sign of Capricornus ♑; *fig.* 14, when in the sign of Libra ♎; and *fig.* 15, when—$14\frac{3}{4}$ years later—he is found in Aries ♈.

The dimensions of the rings, as also their distances from each other and from Saturn, will be found in sec. 58. This ring system is, however, no great source of gratification to the inhabitants of Saturn, as it is only visible in the middle equatorial regions of the planet. It does not shine by night, only during the day, or a little while after sunset and before sunrise, and even this in general only during the summer. For at night the whole ring is shaded by Saturn; and in winter, instead of illuminating the planet, it casts a shadow upon the side of the planet opposite to the sun, covering an area of many millions of miles, and lasting in part almost fifteen of our years. On the other hand, the inhabitants of the surface of the ring will perceive Saturn's hemisphere in their horizon, of enormous size, and should they be on the very edge of the ring, they will perceive the planet in their zenith about 20,000 times larger than the sun. The floor itself upon which they stand, reaches to the right and to the left, visible up to the heavens, closing beyond the planet, thus affording beyond all question an entirely unique and most magnificent spectacle.

38. Every planet revolving about the sun must have at one time a period of least, and at another one of greatest distance from the earth. In the first case the planet is said to be in its *perigee*, in the second in its *apogee*. The two inferior planets, Mercury and Venus, are in their perigee at inferior conjunction, and in their apogee at superior conjunction; the superior planets are in apogee at conjunction, and in perigee at opposition

On account, however, of the different eccentricities, as well as the different inclinations of the planetary orbits to that of the earth, the perigee and apogee for each planet cannot be always the same. The consequence of this is, that seen from the earth, the planets do not always appear of equal apparent size. Each planet must appear greatest in its perigee, and least in its apogee. The difference for all the planes is approximately represented in *pl.* 14, *figs.* 16–35, according to the scale AB, whose larger divisions measure 25 seconds, the smaller $2\frac{1}{2}$. This difference at the time of perigee is the following:—

Distance of the Planets from the Sun, and apparent Diameter at time of Greatest Perigee.

Figs.	Planets.	Distance in Millions of Geographical Miles.	Apparent Diameter in Seconds.
16	Venus,	20	62
18	Jupiter,	316	46
20	Saturn,	644	20
22	Mars,	28	23
24	Mercury,	160	12
26	Uranus,	1,392	4
28	Pallas,	88	$3\frac{1}{2}$
30	Juno,	80	$2\frac{1}{3}$
32	Ceres,	124	2
34	Vesta,	92	$\frac{4}{5}$

And for the time of Greatest Apogee.

Figs.	Planets.	Distance in Millions of Geographical Miles.	Apparent Diameter in Seconds.
17	Venus,	140	$9\frac{1}{2}$
19	Jupiter,	520	30
21	Saturn,	892	$15\frac{1}{2}$
23	Mars,	216	$3\frac{1}{3}$
25	Mercury,	120	$4\frac{2}{5}$
27	Uranus,	1,696	$3\frac{4}{5}$
29	Pallas,	368	$1\frac{1}{2}$
31	Juno,	360	$1\frac{1}{5}$
33	Ceres,	328	$\frac{4}{5}$
35	Vesta,	296	$\frac{2}{5}$

39. *Pl.* 14, *figs.* 36–45, exhibits approximately the apparent size of the sun, as seen from the planets at their mean distances from him. To this we will add the apparent diameters in seconds.

Apparent Size and Diameter of the Sun, as seen from the Planets.

Figs.	Apparent Size in Order.	Apparent Diameter.
36	Mercury,	1° 22′ 49″
37	Venus,	0 40 32
38	Earth,	0 32 3
39	Mars,	0 21 2
40	Vesta,	0 13 35
41	Juno,	0 12 0
42	Ceres and	0 11 34
	Pallas,	0 11 33
43	Jupiter,	0 6 10
44	Saturn,	0 3 22
45	Uranus,	0 1 40

The figures above are also constructed on the scale AB, only the greatest divisions amount to 1500, the smaller to 150, and the smallest to 15 seconds. Hence it follows that to Uranus the sun appears $49\frac{1}{2}$ times smaller than to Mercury, and to Jupiter $5\frac{1}{2}$ times smaller than to the earth.

Finally, *figs.* 46–54 show the true diameter of the earth's moon, and of these planets, compared with the true diameter of the earth. If in *pl.* 14, *fig.* 46, the diameter of the earth be taken as equal to 100 parts, then will the other diameters be as follows :—

Moon of the earth,	*fig.* 47,	26 parts.
Venus,	48,	98
Mars,	49,	52
Mercury,	50,	39
Pallas,	51,	26
Ceres,	52,	20
Juno,	53,	18
Vesta,	54,	3

Principal Phases of a Transit of Mercury or Venus over the Sun's Disk, and manner of observing them.

40. The general theory of the transits of Venus and Mercury has been already explained in section 29, by reference to *figs.* 6, 7, 8, *pl.* 9. It still remains to show by *fig.* 55, *pl.* 14, the mode of observing such a phenomenon. When, as is generally the case, an astronomical telescope is employed, which represents all objects inverted, the attention of the observer, before the commencement of the transit, is to be directed to the right border of the sun's disk. The straight line, passing through the figure, represents the course that Mercury, for instance, takes across the sun. When arrived at *d*, the *first external contact* of the limbs of Mercury and the sun, or the so-called *external immersion*, takes place; at this time the

transit begins. Arrived at *c*, we have the *first internal contact* of the limbs of Mercury and the sun, or the so-called *internal immersion;* Mercury has now entered altogether on the disk of the sun. When the planet reaches *b, the second internal contact,* or the so-called *internal emersion,* takes place; at this moment the planet begins to leave the sun. Finally, the arrival of Mercury at *a,* brings about the *second external contact,* or the *external emersion,* the transit ceasing at this moment.

In reality, or when observed with the terrestrial telescope, these four phases follow in a direction from left to right; in other words, Mercury occupies in succession the points *a, b, c, d.* The case is precisely the same in a transit of Venus. The method of obtaining the sun's parallax, and hence the mean distance of the earth from the sun, from such observations instituted at different places on the surface of the earth, cannot be here intelligibly exhibited and explained, as geometrical considerations combined with trigonometrical calculations are absolutely necessary.

The Total Eclipse of the Sun, June 4th, 1788.

41. *Fig.* 56, *pl.* 14, furnishes a representation of the extent and course of the moon's shadow over the earth's surface during the existence of a total eclipse of the sun. For our illustration we have taken the total eclipse of the sun, which was observed on the 4th of June, 1788, in the eastern hemisphere of the earth. The figure represents, in the first place, a broad curved line or zone of intense black. This zone covers all places at which the total eclipse was seen. To all places in its very central line, the eclipse was annular and of longest duration, while the localities on its external border saw a total eclipse only for a moment. Parallel to this zone, and to the north and south of it, lines are drawn with these indications, 9, 6, and 3 digits obscuration, with corresponding shading. They include all those places where the eclipse affected 9, 6, and 3 digits of the sun's disk respectively; to the north of the zone of total obscuration, the sun being eclipsed on its inferior, and to the south of it on its superior limb, and this in proportion to the proximity of the place to the central zone. The upper and lower arcs, GH and JK, cut all those places which saw, for a moment only, the beginning or the end of the entire eclipse. The arcs uniting the ends of GH and JK, cut the places which—the westerly at sunrise, the easterly at sunset—perceived just half the eclipse (or 6 digits). The other curved lines cut all those places where the beginning, the middle, or the end was perceived at sunrise, or the beginning, the middle, or the end at sunset. A glance at the chart consequently shows that this eclipse was visible in the whole of Europe and Asia, except Kamtschatka, the greater part of Siberia, and the island Celebes, as also in north and middle Africa.

42. The explanation of the origin and progress of eclipses of the sun and moon has already been given in section 22. To project any other great solar eclipse upon a map, as has been done in *fig.* 56, it will be first of all necessary to call in the assistance of a terrestrial globe, and likewise to

obtain by previous calculation, several places on the earth's surface, where, for a given time of the place, a central (total or annular) eclipse will happen. In other words, it will be necessary to know beforehand the course of the centre of the moon's shadow over the earth's surface. Cut from thin brass plate or pasteboard a circle, whose diameter is equal to the diameter of the globe, multiplied by the difference of the *apparent* radii of the sun and moon, and divided by the parallax of the moon. Next, place horizontally upon the globe a ruler, and upon the ruler the above-mentioned circle. Let A be a place on the globe, which for a given local time has the sun in its zenith, and let B represent a place which, according to the preceding calculation, is to see a central eclipse at this same time; adjust the globe in such a position that A occupies its highest point, and for this position of the globe, move the circle upon the inner horizontal ruler in such a manner that the centre of the circle shall lie perpendicularly above the point B. If we suppose straight lines to be drawn from all points in the circumference of the circle, perpendicular to its plane, then those vertically under the plane will inclose that space on the globe which, for the time in question, will be covered by the full shadow of the moon. We must now place the still horizontal ruler in such a manner that the centre of the circle shall constantly be vertically above the successive points B′, B″, B‴, &c, which for given times have a central eclipse. The globe must be turned at the same time in such a manner that its highest point is continually that which at the given times has the sun in its zenith. We can thus mark the entire path of the full shadow and its bounds on the globe, from which it may be transferred to a map. Cut now a circle whose diameter is equal to the diameter of the globe, multiplied by the sum of the apparent radii of the sun and moon, divided by the moon's parallax, and proceed with this circle as before; we shall in this manner obtain all those places which lie before the northern and southern borders of the half shadow, and which consequently only perceive a contact of the edges of the moon and of the sun.

III.—Physical Astronomy.

Rotation of the Earth; its Spheroidal Form; Centrifugal Force; Simple Proof of the Spheroidal Shape of the Earth; Local Variation of Gravity.

43. The daily motion of the starry heavens is only apparent, being a consequence of the actual turning of the earth on its axis, called its *rotation*. This rotation proceeds in a direction from west to east, since we see the apparent rotation of the heavens taking place in the opposite direction, or from east to west. Let, in *fig.* 7, *pl.* 6, the greater circle, KIH*kih*, represent the stationary heavens, and the smaller circle, the rotating earth with its centre C. The point *o*, in the upper part of the circle, will then, by its rotation, be made successively to assume the positions *o*, *o*. The consequence will be, that the horizon of *o* will be first H*oh*, then J*oi*, then K*ok*,

&c. The place *o* will consequently first see the part H*kih* of the heavens, then JH*ki*, then KJH*k*, &c. Now, since we do not perceive the motion of the earth, we are led to imagine that it is the heavens that move, which, however, is only an illusion caused by the earth's rotation.

The flattened shape of the earth is also a consequence of its rotation. It is known from the theory of physics, that all parts of any body driven round in a circle with uniform velocity, endeavor to recede from the centre of this circle, which effort is called the *centrifugal force*. Let, in *fig.* 6, *pl.* 6, AMBN represent an elastic globe with an axis AB, passing through the centre C. If now the globe be turned rapidly about AB, all its parts will move the faster, the more remote they are from the poles A and B, or the nearer they are to the equator MN; A and B moving only on themselves as poles. With a more rapid motion there will be an increase of centrifugal force, and those parts of the globe lying near the points M and N will separate more from the axis of rotation AB. Hence the spherical globe, AMBN, will finally assume the ellipsoidal shape, *m*B*n*A, and appear depressed or flattened. The earth, when first set in motion, must have been in precisely the same condition as the above globe, assuming, however, that at that time its matter was in a fluid or semi-fluid state.

44. Thus the earth is not a perfect sphere, but an elliptical spheroid, in which the curvature of a meridian section at the equator is sensibly greater than at the poles, shown by measurements of degrees of latitude. Let NABDEF (*pl.* 6, *fig.* 9) represent a meridian section of the earth, C its centre, NA, BD, and GE, each a meridian arc, corresponding to a degree of latitude or to a degree of change in the meridian altitude of a star. Finally, let *n*N, *a*A, *b*B, *d*D, *g*G, *e*E, be the direction of the plummet at the places N, A, B, D, G, E, of which N is situated in the pole, and E in the equator. If now any two neighboring vertical lines, as *n*N and *a*A, *b*B and *d*D, *g*G and *e*E, be prolonged to their intersections in X, *y*, *z*, then the angles NXA, B*y*D, G*z*E, will each amount to a degree, and consequently be all equal. Thus the small arcs NA, BD, GE, may be considered as circular arcs described about X, *y*, *z*, as centres. The points X, *y*, *z*, are called the *centres of curvature*, and the lines XN or XA, *y*B or *y*D, and *z*G or *z*E, *radii of curvature*, by which the curvature at these points is determined and measured. Geometry teaches us that the intersections of all these vertical lines do not, as in the sphere, all fall in C, but must lie in a certain curve, X*yz*, called the *evolute*. Experience has now shown that the terrestrial meridian is an ellipse, having for its major axis the equatorial diameter EF (*fig.* 9), and for its minor axis, the axis of the earth NS. This agrees also with the ratio of increase of the degree from the equator towards either pole. The radius of curvature at E is the least, that at N the greatest. The dotted lines in *fig.* 9 represent the parts of the evolute belonging to the other quadrants. It is to the celebrated Bessel that we owe the most recent and authentic results from measurements of degrees According to him, a mean degree of the meridian is equal to 57013.109 toises (364,576 English feet); half the major axis, or half the equatorial diameter to 3272077.14 toises (20,923,624 English feet); and half the minor

axis, or half the axis of rotation to 3261139.33 toises (20,853,681 English feet). Consequently the flattening of the earth's spheroid amounts to almost $\frac{1}{300}$.

45. One important consequence of the centrifugal force is the local variation of gravity. It has actually been observed that there is a difference in the gravity or weight of the same body, when brought in succession to places of different geographical latitude. The methods by which these variations of gravity can be indicated, and their magnitude determined, are both statical and dynamical. The statical method consists in bringing the gravity of the weight in equilibrium with some natural force of entirely different character, upon which the local situation exerts no influence. Such a force is the elasticity of a spring. Let ABC (*pl.* 6, *fig.* 10) represent a strong beam of brass, standing on a firmly connected foot, AED. In this latter a flat plate of agate is inserted, and the whole foot rendered capable of being placed in a perfectly horizontal position by a water-level. To C is fastened the spiral spring G, carrying at its lower extremity the polished weight F, the length and strength of the spring being so adjusted that, even in the highest geographical latitude, the weight attached shall not at any time touch the agate plate D. If now the apparatus in perfect order be carried to a place of less geographical latitude, and again erected, it will soon be perceived that the weight F, loaded with the same additional weights as before, will no longer have power to stretch the spring to the degree necessary for bringing about contact between the weight and agate plate. It will therefore be necessary to add more weight, and this addition will evidently measure the difference of gravity in the two places, in so far as it operates on the sum of the suspended matter, that is, upon the sum of the weight F, and the half weight of the spiral spring G.

The dynamical method, on the other hand, consists in determining the velocity which is communicated in a second to a freely-falling body, by that force which draws a given heavy body to the earth. This velocity can only be determined indirectly by observations, as the oscillation of a pendulum. It is shown by the laws of mechanics, that when the same pendulum oscillates in two different places, and consequently under the influence of different forces of gravitation, the intensities of gravitation will be to each other as the squares of the numbers of oscillations made in a given time, and hence their ratio is readily determinable.

Compound Motion; Parallelogram of Forces.

46. Two or more forces acting on the same body in different directions cause it to assume a *compound motion.* If, however, these forces act on each other in such a manner that no motion can result to the body, they are said to hold one another in *equilibrium.* If any two forces act upon the same body in directions forming a known angle with each other, and with known intensities, it is evident that in its course it can obey exclusively neither the one nor the other of these forces. We must therefore investi-

gate the direction and velocity with which the body will move forward. This is easily done by representing the given directions and velocities by the two straight lines, AB, CD (*pl.* 6, *fig.* 11), completing the parallelogram ABCD, and drawing its diagonal AD. AD, by its position with respect to AB and AC, will then give the desired direction, and by its length the desired velocity of the motion of the body. This construction, so important in mechanics, is called the *parallelogram of forces;* AB and AC, the *lateral forces;* and AD the *mean force,* the *resulting force,* or simply the *resultant.* It has been previously mentioned (section 32) that in astronomy a very important application is made of the parallelogram of forces.

Refraction; Morning and Evening Twilight.

47. *Refraction* or *bending of rays* is of great importance in astronomical observations, as it causes the apparent to differ from the true altitude of a star. The atmosphere, like any other transparent body, turns an obliquely incident ray of light, SA (*pl.* 6, *fig.* 17), from its rectilineal direction—in other words, it bends it. Thus a ray of light, SA, coming from a rarer medium (the ether), and incident at a point, A, upon a denser medium (the atmosphere), is bent towards the perpendicular BAC at the point of incidence, just in proportion to the density of this medium into which the light passes. Suppose now an observer to be situated at any point, A, of the earth's surface, KA*k* (*fig.* 16); furthermore, let L*l*, M*m*, N*n*, represent successive strata of decreasing density, into which the atmosphere may be supposed to be divided, these evidently being spherical layers concentric with the earth's surface, KA*k*. Finally, let S represent a star beyond the external limits of the atmosphere. If now there were no atmosphere, the observer at A would see the star in the direction of the straight line AS. In reality, however, the ray SA begins, as soon as it reaches the atmosphere at *d*, to take a more inclined direction, *dc*, according to the above-mentioned law of dioptrics. This change of direction at first, owing to the extraordinary rarity of the outermost layers of the atmosphere, is very slight, but increases as the ray approaches the earth, entering successively into denser and denser strata, and the refraction becoming accordingly greater and greater. Thus, instead of following the rectilineal direction S*d*A, it describes a curve S*dcba*, which becomes more and more concave, finally reaching the earth, not at A, but at a point *a*, nearer to S. *This* ray consequently does not come to the eye of the observer. The ray by which the observer at A perceives the star S, is not S*d*A, but another ray, which, in the absence of an atmosphere, would have reached the point K, behind the observer. Now, however, by the refractive power of the atmosphere, it is bent into the curved line SDCBA, actually reaching the earth at A. It is a well-known law in optics, that every object is seen in the direction which the ray from the object has at the time of its entrance into the eye, the intermediate course of the ray not coming into account. The star S will therefore be seen, not in the direction AS, but in the direction of the straight line A*s*, tangent to the curve SDCBA

at A. Since the curve described by the refracted ray has its concavity inferior, the tangent line As must lie above the unbroken ray AS; consequently the star S will, by means of the refracting atmosphere, appear higher above the horizon AH than it would were there no such atmosphere. Moreover, since the direction of the strata of air is the same in every direction about A, the ray cannot deviate laterally, but must always remain in the same vertical plane, SAC′, passing through the eye, the star, and the centre of the earth.

From what precedes it is evident that refraction causes all the heavenly bodies to appear *higher* than they really are. Therefore, a star actually below the horizon may, by refraction, be raised above it, and become visible, which could not occur without the refracting atmosphere. Thus, for example, the sun, when actually at P, below the horizon AH of the observer, may be rendered visible by the curved line P*qr*A, of which A*p* is the tangent, so as to be referred to *p*. The amount of the astronomical refraction (to be distinguished from terrestrial refraction), for any given altitude in the heavens, depends mainly upon the character, density, temperature, and moisture of the atmosphere; and for this reason the accurate determination of refraction for all heights, particularly for moderate ones, is one of the most difficult problems of physical astronomy. The following general considerations alone can here be mentioned: In the zenith there is no refraction, that is, it is equal to Zero; consequently, a star directly overhead will be seen in its true direction, or as if no refracting atmosphere surrounded the earth. The astronomical refraction increases from the zenith to the horizon, at first very slightly, afterwards more decidedly, so that a star situated near the horizon will appear more distant from its true place than one at a greater altitude. The mean amount of refraction for a celestial body, midway between the zenith and horizon, or at an altitude of 45°, is only 57 seconds, an amount scarcely sensible to the naked eye; but in the horizon, where refraction is greatest, it amounts to 33 minutes, which is more than the greatest apparent diameter of the sun or moon.

48. A prominent consequence of the refraction and deviation of the rays of light is the *morning and evening twilight.* Night, as is well known, does not immediately follow the day, nor the day night; after the setting of the sun, his rays still penetrate the higher regions of the atmosphere, losing themselves in space. The night thus comes on gradually. This prolongation of day is known commonly as twilight, produced partly by reflection, partly by refraction. Let SO (*fig.* 22, *pl.* 6) be a ray of sunlight entering the atmosphere at O; then, instead of following the original direction, and leaving the atmosphere at M, it will be diverted from its course or become broken. This deviation will be the greater the further the ray penetrates into the lower strata, which are denser as they are situated nearer the earth, so that the ray will describe the curve OG. In like manner, the ray SZ will become a curve from Z to D. Since, as has already been shown in *pl.* 6, *fig.* 16, this refraction is most considerable in the horizon, the sun appears to rise earlier and set later than is actually the case, by which means the day is lengthened and the night shortened. Before the rising of the sun, a

part of his light will be reflected from the atmosphere to the surface of the earth. Thus, in *fig.* 22, let MGBD be the earth, and G a point on its surface for which the sun is just about to rise. It is now evident that the horizon HGR, of the point G, receives light from every part of the heavens, whether direct or reflected ; consequently the point A, for which the sun has not yet risen, has above its horizon the indirectly illuminated part, KLR, of the heavens. The morning redness is more brilliant at K, becoming gradually feebler towards R. The point B, on the contrary, has no light at all, and it is there midnight. The cause of evening twilight may be explained in the same manner, and it will be perceived that for the point D, where the sun is just setting, the whole horizon is still bright ; while for the point C, the part TNX of the heavens is only indirectly illuminated. A circle in the heavens, parallel to the horizon, and at a distance of 18° below it, is called the *crepuscular* circle, or circle of twilight.

Let the point M (*fig.* 22) represent Leipzig, and the time be exactly noon ; for the place G, situated 90° west, it will be past 6 o'clock A.M. ; for the place Y, 45° west, it will be 9 o'clock A.M. ; and to this latter the sun, on account of refraction, will appear at J. It will moreover be seen that for a place III., situated 45° east, the sun will appear at E, and that it will there be already 3 o'clock P.M. Finally, it will be readily understood, that while the earth moves about its axis, whose north pole is P, from west to east, or in the direction of the arrows, it must seem as if the sun, in an inverse order, attained successively the points F, J, S, E, U. *Fig.* 22 has been drawn to represent the time of the equinox, when the sun appears to describe the equator.

The morning and evening dawn or twilight is, in conclusion, not only more or less different in the same place at different seasons, but also different at places of different latitudes for the same season.

The Tides.

49. Another very remarkable phenomenon, produced by the attraction of the sun and moon upon the surface of the earth, is the *ebb and flow of the tide*, that well-known and generally regular motion of the sea, which results in a considerable variation of its height twice every day. On the coast of a great and open sea, as the North Sea, the phenomena of ebb and flow will take place in the following manner :—At the time when the water is highest, or at *high tide*, no change will be perceptible for some minutes. Gradually the water begins to run off westward, slowly at first, then with a continually increasing velocity, which reaches its maximum in about three hours. After this the fall continues for three hours with decreasing velocity, so that in a little more than six hours from the time of highest tide, *low tide* takes place. The sea, after remaining at this stage for some minutes, again begins to rise for six hours, and indeed in the same manner as it fell, so that in a little more than six hours from low tide, high tide again prevails. The rise of the water is called the *flow* of the tide, and

the falling the *ebb*. In this manner the whole phenomenon is incessantly repeated in periods of 12 hours and 25 minutes. The difference of elevation of the water at high tide and at low tide is not the same in all places at the same time, nor in one and the same place at all times. This difference, for example, on the German coast of the North Sea, amounts to 13 feet; while at the western end of the Straits of Dover it is sometimes more than 40 feet. The position of the coast, and the direction of the wind, change not a little the regular course of the whole phenomenon. Apart, however, from these local and temporary influences, a *monthly* and a *yearly period* are plainly evident. There is a greater difference between high and low water at the time of new and full moon, than at the time of the quadratures; and furthermore, this difference is more considerable when the sun and earth are nearest to each other, than when most remote. From this there cannot be the slightest doubt that the sun, and more particularly the moon, produce the ebb and flow of the tide.

For the proper elucidation of this phenomenon, suppose the earth's surface to be covered equally with water, and let us inquire what shape this watery surface will assume when the earth, on account of the attraction, begins to fall towards the moon; we will here have reference only to the influence of the latter, as being the most important. It is evident that those portions of the water will be attracted the strongest, which lie nearest the moon M (*pl.* 6, *fig.* 23), and consequently the water surrounding the earth will be heaped up highest at that place, O, which has the moon in its zenith. Here, then, where a mountain of water has arisen, the height of the water will be greatest, decreasing, however, more and more in every direction, reaching the minimum at those points, Z and Z′ (at time of full moon V and V′), which have the moon in the horizon; at the point O′ of the earth, which has the moon in its nadir, there will also be an elevation of the water: this point will be attracted least, and consequently will remain further behind the other points. Hence it follows that there will be a rise of the water at the two points, O, O′, of the earth, distant a whole diameter from each other, and lying in the straight line connecting the centres of the earth and moon. From these two points, the height of the water will decrease according to a certain law, until finally it will be lowest in the points of that great circle which has the two points of highest water for its poles; that is, as before mentioned, in all those places which have the moon in their horizon. Now, although the earth is not a globe entirely surrounded by water, yet by far the greatest portion is covered with water; and the waters of the sea will thus be heaped up in those points which have the moon in the meridian, whether at the inferior or superior culmination. Since the moon, on account of its own motion and the rotation of the earth, culminates every 12 hours and 25 minutes for one and the same place, the phenomenon known as the ebb and flow must continually return within this period. Nevertheless, the time of flood does not exactly coincide with that of the culmination of the moon, which at first may appear strange; but when we reflect that on account of the inertia of the material, the mass of water cannot immediately follow the apparent motion of the moon, that apparent anomaly will be

explained. That the flow in different places of the earth follows sometimes sooner, sometimes later, the culmination of the moon, is to be ascribed to local causes, as has been satisfactorily ascertained by means of many accurately conducted experiments.

Not only the moon, but also the sun, exercises an attraction on the water, and the attractive forces of the sun and moon must co-operate at time of new and full moon, and act against each other in the quadratures. That at full moon a high tide must occur, might at first appear singular, until explained by the fact that, on the side of the earth opposite to the moon, an elevation of the water necessarily occurs. Thus is explained the *monthly period of ebb and flow.* The tides occurring at the time of the syzigies in O and O′, are commonly called *spring tides;* those at the quadratures E, E′, *neap tides.*

Finally, there are several causes of the *yearly period* of ebb and flow, but we shall here only mention those which depend on the varying distance of the sun from the earth. Higher tides will take place in the winter than in the summer months. Since the moon can never separate more than 30° from the celestial equator, it is evident that within that terrestrial zone included between 30 degrees of north and south latitude, the tides must be greatest. This is confirmed by observation, since in the polar seas the entire phenomenon disappears. From what has been said, the conclusion is readily deducible—that the ocean alone, with the open and large seas in connexion with it, can have tides; for supposing the moon to be above the Caspian sea, for instance, then its waters will be attracted; yet, on account of the small extent of surface, this lunar attraction will be everywhere equal, so that an elevation of any particular part cannot take place.

The Resistance of the Ether; its Influence on the Motion of Comets.

50. The apparent course of the inferior and superior planets has already (*pl.* 6, *figs.* 24, 25) been explained. Some attention will here be directed to a circumstance of great importance to the planets, and particularly to the comets. For a long while it was believed that the spaces between the heavenly bodies were absolutely empty, or that a perfect vacuum existed there. This supposition, however, does not seem to be confirmed, at least with respect to the interspace of our planetary system. It is well known that all bodies fall with equal velocity in a perfect vacuum: moreover, the denser the air, and the rarer the body moving in it, the more readily the latter loses its original velocity, since it must experience a greater resistance than another body of greater density moving in the same medium. This must be true with regard to the planets. As these have shown no diminution in their velocity produced by the resistance, we must suppose one of two things: either that the interspaces of our planetary system are absolutely empty, or that if a medium really exists, it is much too rare, in comparison with the density of the planets, to produce any retarding

influence on their motions. The comets, however, which are known to be bodies of very slight density, may experience some retardation, even if it be very slight, from the rare ether existing in space. The continual abbreviation of the period of revolution of Encke's comet, already several times returned, observed, and calculated, indicates conclusively enough that space is filled by a medium, and consequently is not absolutely empty. This abbreviation of the period of the above mentioned comet, is evidently a consequence of the resistance which the ether opposes to the course of the comet. The comet itself may by this means experience, one day or other, a very destructive catastrophe. Since it meets a resistance in its course around the sun, it naturally will not be able to retain its original orbit, but must by degrees move in arcs which lie nearer to the sun than those previously described in similar times. The orbit will, therefore, remain no longer an ellipse or a closed curve, but must become a spiral, terminating in the sun itself, since the comet will be more and more affected by his attraction, and consequently approach nearer and nearer (*pl.* 6, *fig.* 26). The immediate consequence of this must be a gradually diminishing period of the comet, which will accomplish its course with greater and greater velocity, until finally it will be lost in the sun.

The Sun's Spots.

51. *Pl.* 9, *figs.* 9-13 represent the black spots seen sometimes, with the assistance of the telescope, on the sun's disk, of greater or less size, irregular shape, and surrounded by an ash grey border, generally of uniform breadth. The solar spots appear frequently to change not only their shape, as shown by *figs.* 10 and 11, but also their position on the sun's disk. They are sometimes very large, and their constant occurrence in connexion with the *solar faculæ* (*fig.* 9), as also their ash grey border, plainly indicate a common origin with these. Thus, for instance, their black spots may be seen to break out in the midst of these faculæ, or, inversely, faculæ arise in the places whence spots have just vanished. These *faculæ* are streaks, which, by their dazzling light, are distinguishable from the rest of the disk, and resemble, so to speak, veins of light.

It is very rare that the spots on the sun are seen at a distance of more than 30° from his equator on each side. At their entrance on the sun's disk they appear very small, and when they come near to the border of the sun, they are seen as black lines, becoming broader the nearer they are to the centre of the disk; they moreover seem to move in almost parallel lines from east to west over the sun's disk: their true motion, however, is from west to east, as they would appear to an eye at the centre of the globe of the sun. A spot generally occupies from 12 to 13 days in crossing the visible disk of the sun. It is then invisible for a period of 14–15 days, but at the expiration of this time it appears in the same place in about 27 or 28 days after the first appearance, to commence its second revolution. The paths of the spots appear towards the 10th of June and 10th of December as

straight lines; on all other days of the year as ellipses, whose convex sides are turned for half a year towards the north, and for the same length of time towards the south, and whose greatest curvature takes place shortly before March 10th and September 10th. Observations on the sun's spots have enabled us to ascertain a rotation of the sun on its axis in a period of $25\frac{1}{2}$ days.

Herschel's hypothesis with respect to the nature of the spots on the sun, appears to be the most probable. He assumes a threefold concentric envelope of the obscure body of the sun proper. This first envelope is the photosphere, or atmosphere of light; beneath it the second, a transparent and very elastic medium; and beneath this layer the third, a cloudy obscure envelope, illuminated on its outer side, and reflecting the light to our eyes. In this manner it forms an ash grey border, which is seen sometimes on the sun without a central spot, whenever an opening may exist in the first, or first and second layers. Whenever this fissure or opening extends, as is generally the case, through the third layer, the dark nucleus of the sun is then perceived, and about it the above mentioned grey border, which is, accordingly, nothing else than the light passing into the opening from the outermost layer, and reflected back from the inner atmosphere to our eye.

The group of spots represented in *fig.* 9, was discovered May, 1799, by Fritsch of Quedlinburgh. The western spot, very near the border of the sun, appeared as a black nucleus of oval shape, with an equally oval nebulous inclosure. Eastward of the oval spot, Fritsch observed another circular one, both united by a so called valley or mountain way, having the appearance of a ring mountain of our moon. From this mountain way run lateral branches, and both appear to the eye whiter and fainter than the rest of the solar surface. The spots, *pl.* 9, *figs.* 10, 11, 12, 13, were discovered by Pastorff, in Frankfurt on the Oder, May 24th, 1828. The largest (*fig.* 10), *abcd*, had at *ab* a diameter of 100 seconds, and at *cd* one of 60. It now appears, however, as a straight line of 392 geographical miles on the surface of the sun, under an angle of almost one second, seen from the earth; consequently, the true diameter of this spot amounted to 39,200 geographical miles at *ab*, and to 23,520 at *cd*. The greatest diameter amounted to more than five diameters of the earth (= to 6880 geographical miles), consequently the surface of this spot contained nearly 928,000,000 square geographical miles. Furthermore, *ef* (*fig.* 10) had an apparent diameter = 110 seconds; *gh* = 60; *no* = 68; *pq* = 30; *ik* (*fig.* 11) = 38; *lm* (*fig.* 12) = 66; *rs* = 24; *tu* (*fig.* 13) = 46; and *wx* = 12. All these numbers multiplied by 392 give the dimensions in geographical miles, altogether equal to an area of 2,496 millions of square geographical miles, or about 17 times as great as the whole surface of the earth.

The honor of the first discovery of the sun's spots appears due to the English astronomer, Harriot, who saw them Dec. 8, 1610. The eminent physician Averrhoes (in the twelfth century) was perhaps the first who saw a spot with the naked eye, erroneously supposed by him to be the planet Mercury. Phrystus of Wittemberg published the first treatise on these spots in 1611; the Jesuit, Father Scheiner, however, sought to appropriate the

discovery. He seems to have exhibited, in May, 1611, the first spot to his pupils in Ingolstadt, where he was professor. Galileo had observed the spots of the sun as early as the beginning of 1611, nearly contemporaneously with Fabricius, and very soon presented correct views of their nature.

Topography of the Moon.

52. The most interesting object visible by a good telescope in the heavens, is certainly the surface of the moon, whose peculiarities, as being of all heavenly bodies the nearest to us, are known best of all. At an early period Galileo, Scheiner, and Hevelius, and afterwards Grimaldi, Riccioli, Cassini, and Lahire, attempted to construct a chart of the moon; the maps of the moon by Hevelius, Mayer, and Schröter, are well known. Lohrmann, however, uniting an intimate knowledge of facts with sound judgment, first published accurate and beautiful maps of the moon, four in number, whose continuation was unfortunately arrested by his death. Beer and Mädler, finally, in 1836, published four large sheets with a general map of the moon, on Lohrmann's plan, indeed, but founded on original observations. Of this general map *pl.* 11, *fig.* 1 is an accurately reduced copy. Our chart represents the moon inverted, or as it would be exhibited to the observer in an astronomical telescope of from 60 to 80 magnifying power. North is consequently below, South above, East to the right, and West to the left. From want of room, and to avoid crowding, the single mountains and craters are indicated by numbers, whose import will presently be explained. On the moon there can be directly distinguished nothing but differences of level and illumination; consequently only *mountains*, *craters*, and *colors*. The two first are exhibited best in the growing and waning moon, when the part to be observed lies near the illuminated border; the colors we see to the most advantage at the full moon. Many of the *ring mountains* have, following Riccioli's example, been named after eminent philosophers; while for the rest, with Hevelius, the names of mountains, rivers, &c., have been borrowed from the earth.

53. The numbers annexed to the names in the following list, indicate the depth or the inner descent of the wall in Paris feet; where a second number, inclosed in brackets, occurs, it indicates the height of the wall above the outer inclosure. All these numbers are derived from original measurements by Beer and Mädler.

I.—Northwestern Quadrant of the Moon.

The Map of the Moon (Fig. 1) to the Left Below.

1	Schubert		
2	Reper		
3	Firmicus	4638	
4	Apollonius	5100	
5	Taruntius	3272	
6	Maskelyne	4362	
7	Sabine	2485	
8	Ritter	3718	
9	Dionysius		
10	Arago	5022	
11	Sosigenes		
12	Cæsar	5082	
13	Ariadäus		
14	Godin	6780	
15	Agrippa	6342	
16	Boscowich		
17	Hyginus		
18	Rhäticus		
19	Triesnecker	5086	
20	Uckert		
21	Condorcet	8410	
22	Hansen		
23	Alhazen		
24	Azout	5300	
25	Picard	4982	(2867)
26	Proclus	7790	
27	Jansen		
28	Vitruvius	4227	
29	Maraldi		
30	Plinius	5904	
31	Ross		
32	Acherusia Cape	4536	
33	Taquet		
34	Menelaus	6164	
35	Sulpic. Gallus		
36	Manilius	7223	
37	Agarum Cape	9666	
38	Eimmart	9683	
39	Oriani		
40	Plutarch		
41	Seneca		
42	Hahn	9095	
43	Berosus	10,722	
44	Cleomedes	8194	
45	Tralles	8202	
46	Macrobius	14,409	
47	Römer	10,864	
48	Littrow		
49	Lemonnier	8475	
50	Bessel	3606	(1464)
51	Linnæus		
52	Conon		
53	Hadley	14,208	
54	Bradley	12,639	
55	Gauss		
56	Burckhardt	13,672	
57	Geminus	11,577	
58	Bernouilli	11,868	
59	Messala	3360	
60	Berzelius		
61	Franklin	7436	
62	Posidonius	5346	(2976)
63	Kalippus	7230	
64	Theätetus	7004	(3312)
65	Aristillus	10,464	(4750)
66	Autolycus	8457	(4485)
67	Cassini	4098	(3870)
68	Struve		
69	Schumacher		
70	Mercurius		
71	Hook		
72	Cepheus	8588	
73	Oersted		
74	Atlas	10,261	(3462)
75	Hercules	10,209	
76	Mason	5705	(3336)
77	Plana		
78	Bürg	6372	(4297)
79	Eudoxus	13,980	
80	Aristotle	10,031	(4266)
81	Egede	320	
82	Endymion	15,690	
83	Strabo		
84	Thales		
85	Gärtner		
86	Democritus	5302	
87	Christ. Mayer	3906	
88	Meton		
89	Euktemon		
90	Scoresby	9216	
91	Barrow	8832	
92	Archytas	3704	

II.—Northeastern Quadrant of the Moon

The Map (Fig. 1) to the Right Below.

1	Pallas	4193	
2	Bode		
3	Schröter	2340	
4	Gambart	2500	(2154)
5	Stadius	630	
6	Copernicus	10,584	(2478)
7	Reinhold	8819	
8	Hortensius		
9	Encke	1698	
10	Kepler	9400	
11	Reiner	9306	
12	Hevelius		
13	Cavalerius	8990	
14	Olbers		
15	Marco Polo		
16	Eratosthenes	14,678	(6204)
17	Gay-Lussac		
18	Mayer		
19	Milichius		
20	Marius	4270	
21	Bessarion		
22	Cardanus		
23	Kraft		
24	Huyghens	16,934	
25	Wolff	11,316	
26	Archimedes	5084	(3636)
27	Timocharis	6786	(3426)
28	Pytheas	(5500)	(2241)
29	Lambert	5580	(2259)
30	Euler	5585	(1062)
31	Diophantus	4000	(2392)
32	Lahire	4788	
33	Herodotus	4032	
34	Seleucus		
35	Briggs		
36	Aristarchus	7058	
37	Helicon	2482	
38	Carlini		
39	Delisle	5586	
40	Wollaston		
41	Lichtenberg		
42	Lavoisier		
43	Kirch		
44	Pico	6624	
45	Laplace	9022	
46	Heraclides	3681	
47	Maupertuis		
48	Bianchini	7936	
49	Sharp	6949	
50	Mairan	7520	(4890)
51	Louville		
52	Gerard		
53	Plato	6810	
54	Lacondamine	3996	(2490)
55	Bouguer		
56	Harpalus	14,872	(2576)
57	Œnopides		
58	Repsold		
59	Harding		
60	Xenophanes		
61	Cleostratus		
62	Timäus		
63	Epigenes		
64	Fontenelle	6372	
65	Horrebow		
66	Anaximander		
67	Pythagoras		
68	Gioja		
69	Anaxagoras	8943	
70	Philolaus	11,604	
71	Anaximenes	7487	
72	Sömmerring	4282	
73	Vasco de Gama		

III.—Southeastern Quadrant of the Moon.

The Map of the Moon (Fig. 1) to the Right Above.

1	Malapert		
2	Cabeus		
3	Short	17,532	
4	Moretus	14,994	
5	Newton	22,362	
6	Casatus	19,514	
7	Klaproth	9365	
8	Wilson	12,954	
9	Gruemberger	13,024	
10	Cysatus	11,900	

11 Blancanus . . . 16,892
12 Scheiner
13 Kircher 16,530
14 Bettinus 11,616
15 Bailly 13,910
16 Hausen
17 Zuchius
18 Clavius 15,792
19 Deluc
20 Maginus 13,553
21 Longomontanus . 13,641
22 Rost 7406
23 Weigel
24 Segner . . . 7617 (6006)
25 Bayer 7572
26 Schiller 11,856
27 Phokylides . . . 8250
28 Wargentin . (400) (1392)
29 Saussure
30 Pictet
31 Street 4188
32 Tycho 16,662
33 William I. . . . 10,389
34 Heinsius 8130
35 Hainzel 10,880
36 Drebbel
37 Schickard . . . 7938
38 Inghirami 11,460
39 Lehmann
40 Nasireddin . . . 10,308
41 Orontius
42 Sasserides . . . 7415
43 Lexell 7236
44 Walter 13,479
45 Hell 5034
46 Gauricus 8730
47 Wurzelbauer . . . 5160
48 Pitatus
49 Hesiodus
50 Cichus . . . 7938 (4848)
51 Capuanus 8022
52 Ramsden . . 3000 (1722)
53 Vitello . . . 4000 (4810)
54 Piazzi
55 Lagrange
56 Bouvard
57 Regiomontanus . . 5964
58 Purbach 7594
59 Thebit 7882
60 Mercator 4358
61 Campanus . . . 6126
62 Hippalus
63 Kies 2292
64 Bulliald 8410
65 Doppelmayer
66 Fourier 8877
67 Vieta 13,739
68 Cavendish . . . 7038
69 Byrgius 6516
70 Mersenius . . . 7890
71 Eichstädt
72 Arzachel 12,750
73 Alphonso . . 6600 (5196)
74 Alpretagius 11,291 (3540)
75 Davy
76 Guericke 1926
77 Lubiniezki . . . 924
78 Agathárchides . . 3456
79 Gassendi 8970
80 Letronne 3015
81 Billy . . . 3183 (2292)
82 Zupus 4399
83 Lontana
84 Sirsalis 9528
85 Crüger
86 Rocca
87 Ptolemäus . . . 7452
88 Herschel 8832
89 Mösting . . 7062 (1524)
90 Lalande
91 Parry 1536
92 Bonpland
93 Fra Mauro
94 Landsberg . 9064 (2802)
95 Euclides
96 Flamsteed . 5479 (1320)
97 Damoiseau
98 Grimaldi
99 Lohrmann
100 Riccioli
101 Hansteen . . 3522 (2649)

IV.—Southwestern Quadrant of the Moon.

Map of the Moon (*Fig.* 1) *to the Left Above.*

1 Schomberger
2 Simpelius 9645
3 Boguslawski . . . 10,468
4 Boussingault

5	Manzinus	9991
6	Mutus	11,525
7	Pentland	
8	Curtius	20,898
9	Pontecoulant	
10	Hanno	
11	Biela	
12	Hagecius	
13	Nearchus	
14	Rosenberger	
15	Blacq	9762
16	Hommel	
17	Pitiscus	9463
18	Baco	11,616
19	Jacobi	9684
20	Zach	11,414
21	Lilius	9286
22	Oken	
23	Vega	
24	Steinheil	11,046
25	Fabricius	7818
26	Nicolai	5874
27	Clairaut	
28	Barocius	11,366
29	Maurolicus	13,314
30	Cuvier	11,272
31	Licetus	12,766
32	Stöfler	10,950
33	Marinus	
34	Fraunhofer	
35	Furnerius	10,100
36	Stevinus	10,782
37	Rheita	13,464
38	Metius	12,372
39	Reichenbach	10,996
40	Neander	7476
41	Stiborius	11,343
42	Riccius	
43	Rabbi Levi	
44	Zagut	
45	Lindenau	11,136
46	Büsching	4218
47	Buch	
48	Gemma Frisius	12,796
49	Poisson	6888
50	Aliacensis	13,624
51	W. von Humboldt	
52	Hekateus	
53	Legendre	7627
54	Petavius	10,158
55	Snellius	6400
56	Borda	10,338
57	Fracastoro	7988
58	Santbech	12,894
59	Piccolomini	14,574
60	Polybius	7278
61	Pons	
62	Fermat	
63	Sacrobosco	11,295
64	Pontanus	
65	Azophi	13,644
66	Abenezra	10,254
67	Appianus	8787
68	Playfair	11,290
69	Werner	14,658
70	Ansgarius	
71	Vendelinus	5046
72	Cook	2959
73	Colombo	7540
74	Magellan	
75	Bohnenberger	
76	Beaumont	5778
77	Theophilus	14,939
78	Cyrillus	
79	Katharina	15,423
80	Kant	
81	Tacitus	9762
82	Almanon	5724
83	Geber	8112
84	Abulfeda	9600
85	Airy	
86	Albategnius	13,943
87	Parrot	
88	Kästner	
89	Maclaurin	
90	Langrenus	11,616
91	Messier	5256
92	Goclenius	4386
93	Gutenberg	
94	Capella	9504
95	Isidor	9005
96	Torricelli	
97	Hypatia	6904
98	Delambre	14,046
99	Hyparchus	
100	Réaumur	
101	Biot	
102	Lacaille	

54. With only a tolerably good telescope, the bright spots of the moon can be determined as mountains, by means of their shadows. Their shadow lies always on the side opposite to the sun, and is the longer the less the altitude of the sun for the mountain. The grey spots were at one time

erroneously supposed to be seas. The distinct brilliant points, so many of which are seen on the full moon, are only rarely elevations; oftener steeply precipitous depressions. The structure of the lunar mountains in general is very different from that which prevails on our earth, in that they present themselves for the most part as circular closed walls, with a hollow sloping cavity. They are called *ring mountains*, as, for instance (*pl.* 11, *fig.*1), Ptolemaeus (III. 87), Alphonso (III. 73), and Archimedes (II. 26); Plato (*fig.* 4). The greater of them are called *walled plains* when they inclose a plane surface: the smallest ring mountains are called *craters*. The most diminutive of these, on account of their small size, could not be represented in *pl.* 11 by mountain streaks, and therefore small circles have been employed for these. They are seen on a larger scale in *fig.* 3, namely, Pliny and Vitruvius. The walled plains occurring most frequently in the southwestern part of the moon, appear to belong to the earlier formations of the moon's surface, since they are unmistakably inferior to later forms of every kind. The light streaks passing frequently through walled plains, as also over the other regions of the moon, are not, as a whole, actual elevations, as they are sought in vain under an oblique illumination, when actual elevations are indicated as such by their shadows.

Next to the walled plains follow, in order of size, the ring mountains proper, which, often truly circular, exist in great numbers. Frequently their wall slopes inwards and outwards in so called *terraces;* and in their interior, they generally present an elevation known as the *central mountain.* The most of these central mountains, however, do not reach as high up as the wall. Where the central mountain stands, the inside is sometimes dark grey; commonly, however, as bright as the outer wall. In the southern hemisphere of the moon, the most of these mountains with their walls and environs are so much alike in color and light, that at full moon nothing more can be distinguished of them. The same thing occurs frequently in the deepest, most conspicuous, and most varied ring mountains and walled plains, sometimes even in the grey spots. These latter, consequently, as for instance in *fig.* I., Mare Crisium, Mare Fœcunditatis, Mare Tranquillitatis, and Mare Serenitatis, cannot possibly be seas. Hence it also follows that the view of the full moon is entirely different from that at the first or last quarter, since here the shadows of the mountains and craters present themselves, while there it is only various colors and their shading that are seen.

Mountain chains occur here and there upon the moon, as upon the earth, but never of so great length. Even those mountains connected with one another, and termed *mountain chains*, have by no means the same valley and hill structures as the mountain chains on our earth, but they approach more to the crater form, and do not run out into various branches. The names of these mountain chains have been derived from those on the earth, as may be seen on the maps of the moon (*pl.* 11, *fig.* 1). The greatest elevations of the following mountain chain are given in Paris feet.

Caucasus	17,138	Altai	12,459
Appenines	16,934	Mountain on Sinus Iridum .	14,022

Pyrenees	11,178	Hemus	6,222
Alps	11,136	Carpathians	5,970
Taurus	8,472	Riphæans	2,580

Again, perfectly insulated mountains, called *cone mountains*, exist in great numbers on the moon. With respect to the grey level regions of the moon, at one time called seas, they are universally intersected by ranges of heights, either long and straight, or running in great free curves. The latter are with some inaccuracy termed *mountain spurs*, since they are not ramifications and extensions of greater mountains, and vanish entirely at full moon, casting a shadow only at sunrise and sunset, by which they are then recognised. The *streaks of light* must be considered as very remarkable and difficult of explanation, many of which run along singly, but most form radiating systems. These streaks of light stretch indifferently over mountains, valleys, and plains, without altering their shape, direction, or color. They are almost always four to twelve miles broad, and vanish under an oblique illumination. Equally singular are the *channels*, those extremely narrow but deep furrows, which run generally in rectilineal directions through plains, and more rarely through mountainous regions. These channels cannot be streams or their beds, nor can they remind us of canals and highways. These channels are indicated by narrow parallel lines on the map of the moon.

As regards the colors of the moon, we can only indicate them on our chart in the most general outlines. At least ten different shades, from dark grey to the most brilliant white, can be distinguished. In general, the elevation is the brighter, and the depression the darker; this relation is, however, sometimes inverted. The brightest spots very rarely belong to the higher mountains; it is rather great depths that shine with uncommon brilliancy.

55. For the sake of giving a clear idea of the appearance of particular regions of the moon through a good refractor of 200–300 magnifying power, we have furnished the figures 2, 3, 4, and 5, which surround *fig.* 1, *pl.* 11. The region *fig.* 2 contains the mountains Caucasus, Calippus, Eudoxus, and Aristotle, found in quadrant I. (*fig.* 1); *fig.* 3, the mountains Jansen, Plinius, Vitruvius, and Littrow, with a part of Mare Serenitatis, also occurring in quadrant I. *Fig.* 4 represents the mountains found in quadrant II. (*fig.* 1), namely, Kirch, Pico, Alps, Plato; as also a part of Mare Imbrium and of Palus Nebulum. Finally, *fig.* 5 represents the mountains Saussure, Pictet, Tycho, Sasserides, and Gauricus, of quadrant III. (*fig.* 1.)

A degree of the equator, or $\frac{1}{360}$ part, is equal to 60 geographical miles; a degree of the moon's equator is equal to $16\ \frac{36}{100}$ geographical miles; the whole surface of the moon is therefore about equal to the area of America.

The visible hemisphere of the moon is represented in *fig.* 1, *pl.* 11, as it appears at the time of mean libration. Consequently only the central parts appear in their true proportions; for nearer the borders all circular crater groups must appear oblong.

It is erroneous to suppose that with better instruments and higher magni-

fying powers, it will be hereafter possible to perceive more and minuter details of the moon's surface (as, for instance, artificial structures) than at present: for with these improvements the difficulties and hindrances will increase in like proportion. We need only refer to the atmosphere of the earth and the borrowed light of the moon. These difficulties are even now experienced in the application of the best telescopes, as the moon, of all the heavenly bodies, is that for which the highest powers are unsuited. It is by means of very accurate and long continued observations that we are to have our knowledge of the moon increased. It is only then that better comparisons with the earlier observations, and more accurate conclusions may be drawn than now, when only since the time of Lohrmann and Mädler the moon has been attentively examined with the more improved refractors. Posterity will be able to verify changes which appear to be taking place on the surface of the moon, and our successors will probably ridicule many of our opinions, and reject them as untenable. One fact is certain, however, that *Selenography* (description of the moon) must commence with generalities and progress to particulars, while *Geography* (description of the earth) pursues the opposite method. Selenography has the advantage of Geography, as we do not possess so good a general view of the earth as of the half of the moon which is visible to us.

To become most readily acquainted with the mountains, craters, &c., of the moon, it will be necessary to examine attentively the moon at the time of the first or last quarter, through a telescope of about 40–60 magnifying power, and to make constant reference to the lunar maps. During the full moon, this, at least to a beginner, is not very satisfactory, as at this time the sun stands directly over the centre of the visible moon's disk, and the shadows of the mountains are not seen. In the first and last quarters, however, the sun moves above and below the centre of the visible disk, and at this time, accordingly, the shadows of the mountains are greatest and most evident.

The Planets Mars, Jupiter, Saturn, and Uranus.

56. *Pl.* 8, *fig.* 18, represents the planet Mars in his not entirely illuminated condition, as seen August 16, 1830, by Sir John Herschel, at Slough, with a 20-foot reflector. We see plainly enough presumptive continents and seas; the first distinguished by their reddish color, characterizing the light of this ever red and fiery planet. In contrast with this color, the seas, if we may so term them, appear of a greenish hue. These spots cannot always be seen with equal distinctness, which is probably owing to the fact of Mars not being entirely free from an atmosphere. This supposition is confirmed by the exhibition of brilliant white spots at the poles of Mars. These spots are probably snow, as they vanish when they have been long exposed to the sun, and on the other hand are largest on emerging from the long night of their polar winter. By observations on the spots, Mars has been found to have a period of rotation in 24 hours, 39 minutes, 21 seconds; and the inclination of the axis of rotation to the ecliptic, amounts to about 30° 18′.

Since the time of Herschel and Schröter, Mädler in Dorpat has first, in our day, carefully and attentively examined the surface of Mars. It is moreover known that Mars alone of all the superior planets exhibits phases to the earth, or some slight deviation from the perfect roundness of his disk.

57. The disk of the great and beautiful planet Jupiter, always appears with dark streaks drawn across in a determinate direction. *Fig.* 19 gives a view of these streaks as observed at Slough with a 20-foot reflector on Sept. 23, 1832; these are, however, by no means the same at all times. Remarkable dark spots also, resembling masses of clouds, are not rare; and from careful and continued observations of these spots, the conclusion has been derived, that Jupiter rotates in 9 hours, 55 minutes, 50 seconds (sidereal time), upon an axis perpendicular to the direction of the streaks. On account of the parallelism of these streaks with Jupiter's equator, their oft-occurring changes, and, finally, from appearances of the spots, it may be maintained that these streaks belong to Jupiter's atmosphere, forming tracts in a tolerably serene sky, and are produced by currents similar to our trade winds. They have, nevertheless, a much more permanent and decided character than the clouds in our atmosphere, which may result from the enormous velocity of rotation of the mighty planet. Moreover, that we perceive in the streaks the proportionally darker body of Jupiter is clear, from the well known circumstance that these streaks do not reach to the very edge of the disk, but fade gradually away before they arrive there.

58. *Saturn* (*fig.* 20) is surrounded by an attendant of entirely unique and wonderful character; for accompanied as he is by seven moons, he is also surrounded by two broad and flat, though thin rings, concentric with each other and the planet. Both rings lie in the same plane, and are entirely separated from each other by a narrow, and from Saturn by a much broader interspace. The interval between the planet and the inner edge of the inner ring amounts to 16,572 geographical miles, the breadth of the inner ring to 29,820, the interval between the inner and the outer rings to 1556, and the breadth of the outer ring to 18,356, and finally the thickness of each ring to 88 geographical miles. *Pl.* 8, *fig.* 20, gives a view of Saturn surrounded by his rings, and with dark streaks on his surface, tolerably similar to those of Jupiter; they are however broader and not so evident, although probably originating in the same cause. The supposition that the double ring of Saturn is a solid and opake mass, is confirmed by the fact that it casts a shadow upon the planet, and is shadowed by it in certain positions with relation to the sun. The parallelism of the streaks with the plane of the ring, makes it probable that the axis of rotation of Saturn is perpendicular to this plane, this supposition also being confirmed by the extended dark spots on the planet. From accurate observations of these spots, the period of rotation has been established at about 10 hours, 29 minutes, 17 seconds.

59. Uranus is too distant for the observation of spots on his surface which might assist in determining his period of rotation. Nevertheless it must be supposed that like Jupiter and Saturn, Uranus possesses a very short term of rotation, since Mädler has plainly discovered a flattening of

the planet's disk, which by measurements instituted has been found to be quite considerable. Consequently by reason of this considerable flattening, the velocity of rotation of Uranus must be very great.

The Comets, Nebulæ, Groups of Stars.

60. *Fig.* 15, *pl.* 8, represents the comet of 1819, which, suddenly emerging from the beams of the sun, appeared to Europe, in the beginning of July, of remarkable size. Arago maintained that the light of this comet exhibited traces of polarization, which can only be exhibited by reflected light. This fact speaks strongly for the theory of Olbers, who maintained that the comets are non-luminous bodies, only rendered visible by the reflected light of the sun. Comets consist of a usually spherical nebulous envelope, with a somewhat brighter nucleus, although occasionally without the latter. Sometimes the nucleus is of great size; thus, for instance, that of the great comet of 1811 had a diameter of at least 560,000 geographical miles. In general the nebulosity does not entirely surround the nucleus, but exists as a spherical hull, elongated on the side of the tail, so that the tail appears as a continuation of the nebulosity. It seems besides, that this nebulous envelope constitutes the chief peculiarity of comets, as many of these wandering stars are seen, some without tails, some without nucleus, none nowever without the nebulosity. The tail is generally found on the side opposite to the sun; at times, however, it deviates from this direction, which may be a consequence of the resistance of the ether in which the comet moves. The length of the tail is very various. Thus for instance the length of the tail of the great comet of 1811 (*pl.* 8, *fig.* 17) amounted on Oct. 12 to above 88 millions of geographical miles. The tails also become broader towards their extremity, and are often divided longitudinally in their middle by a dark line, so that it seems as if the tail were double. This was plainly perceived on the 10th of Sept. 1811 in the great comet, as shown in *fig.* 16. The sun undoubtedly produces the tail, as this is always first visible when the comet approaches the sun, becomes larger as the approximation increases, and again diminishes with the gradual increase of distance between the two bodies. Consequently the tails appear, for the most part, to consist of very thin vapor developed by the heat of the sun from the nucleus of the comet. The alterations arising from this cause, which, according to numerous observations, must often be enormous, and may take place even within a few days, doubtless produce the changes observed in the size, shape, and brilliancy of comets. When a comet becomes visible to the naked eye, it is generally seen but a short time, and has a very different course in the heavens from the planets, though it follows the usual daily motion of the heavens. Formerly, on account of the rarity of comets, their remarkable appearance, and their course, it was supposed that they were not true heavenly bodies. Newton, however, first showed that they, like the planets, are heavenly bodies belonging to our solar system. Like the planets, they describe, according to the same laws,

orbits around the sun. The eccentricity of their orbits is very great. It is now also known that telescopic comets, or those only visible to the eye when assisted by a good telescope, occur in far greater numbers than others, and that multitudes of them are probably always present in the space belonging to our solar system.

There are thus far, only three comets whose return has been calculated several times, and whose orbits are accurately known. The first of these is Halley's comet. Halley found that the comets of 1456, 1531, 1607, and 1682 were one and the same, which, he predicted, would return in the beginning of 1759. His prediction was nearly fulfilled. It again appeared in 1835, and is next expected in the end of 1911. The period of revolution of this comet, which can approach within 48 millions of miles of the sun, and recede from him 2920 millions of miles, embraces 76 years. The inclination of its orbit is 17° 44′, and its eccentricity is $\frac{9\,7}{1\,0\,0}$ of the semi-major axis. The motion of this comet is retrograde.

The second comet, discovered by Pons in Nov. 26, 1818, is the direct comet of Encke, with the very short period of $3\frac{1}{2}$ years. Encke found that it had been already observed in 1786, 1795, and 1805, that its perihelion distance was 26 millions of miles, its aphelion 340 millions, the inclination of its orbit 13°, and the eccentricity $\frac{8\,5}{1\,0\,0}$ of the semi-major axis. The predictions of later reappearances of this comet, whose course is affected by the resistance of the ether (sec. 50), were fulfilled in 1825, 1828, 1832, &c.

The third, also a direct comet, was discovered by Biela, 28th Feb. 1826, and named after him. This comet revolves in $6\frac{3}{4}$ years about the sun. Its aphelion distance amounts to 508 millions of geographical miles, while its perihelion comes very near the earth's orbit. This, as is well known, is the comet which in 1832 passed near the earth, and on that account excited universal apprehension. The inclination of its orbit amounts to 13°, and the eccentricity to $\frac{7\,4}{1\,0\,0}$ of the semi-major axis.

Besides these three comets, there are some others recently discovered, whose periods have been found with great accuracy. Their return in the calculated time must, however, be determined by experience. Of these, the best known is the one discovered in the constellation of the Fly, by Olbers, March 6, 1815, and named after him. The motion of this comet is direct. It approaches to within 100 millions of geographical miles of the sun, and recedes to a distance of 2840 millions. The inclination of its orbit amounts to 44°, its eccentricity to $\frac{9\,3}{1\,0\,0}$ of the semi-major axis, and its period to a little more than 74 years. Its re-appearance may consequently be looked for about the year 1889.

While in earlier times comets were looked upon as harbingers of misfortune, or as indicative of Divine wrath, more recently the fear has been excited, lest, on account of their great number, and the various positions of their orbits with respect to that of the earth, a comet may at some time or other come in contact with the earth. This fear, however, Olbers, more than 40 years ago, by his copious investigations of the numbers and orbits of comets, sought to remove as far as possible.

In conclusion, it remains to say that very recently, two more great and

beautiful comets, namely, those of February, 1843, and May, 1845, have appeared and been carefully examined.

61. We turn now to several interesting objects of the starry heavens, which are represented on the left and right sides of *pl.* 8. *Fig.* 1 is a crowded group of stars of irregular outline, seen in the constellation of Hercules, under a right ascension 248° 45′, and north declination of 36° 48′. Stars of the 10th to the 15th magnitude stand very close together, the diameter of the whole amounting to about 8 minutes.

We have already referred in general terms, in sections 15 and 16, to the groups or clusters of stars, as also to nebulous stars and nebulæ. *Fig.* 2 gives a representation of a beautiful circular group of stars in Aquarius, resolvable near the centre by a good telescope, and seen under 321° 15′ right ascension, and 1° 34′ south declination. Towards the centre it is very clear and uniformly brilliant, although the stars do not stand thicker here than towards the border; the central brightest part amounts to six seconds of diameter.

Many groups of stars are fan-shaped, as in *fig.* 3 or *fig.* 4, which latter occurs in the constellation Cancer. The round nebula (*fig.* 5) is found in Ursa Major. In Gemini, under right ascension 109½°, and north declination 26° 26′, there is a nebula (*fig.* 6) whose central star has a great, irregularly oval atmosphere. In Leo Major, 167¾° right ascension, and 41½° north declination, may be perceived a star (*fig.* 7) in the middle of an elliptical nebula, very much pointed at the ends. Two other nebulæ (*figs.* 8 and 9) occur in Monoceros; one of them (*fig.* 9) of right ascension 97½°, and south declination 8° 53′, is a star of the 12th magnitude, with a luminous nebulous train of about one minute in length, not unlike the tail of a comet.

Two and even more stars are often seen enveloped in one nebulous mass, evidently belonging to them both, standing in the two foci or the two vertices of the elliptical nebula. One of this kind is to be met in Canes Venatici, under right ascension 192¾°, and north declination 35° 47′, where the two stars (*fig.* 10) are of the 10th magnitude; in Sagittarius there is a bright elliptical nebula (*fig.* 11), with a star in each of the foci. In the constellation Auriga, a nebula with three stars is observable, which is round (*fig.* 12) according to some, but triangular (*fig.* 13) according to others. *Fig.* 14 represents the great nebula in Andromeda, figured also from another view on *pl.* 13, *fig.* 10.

The Aurora. Mock Suns and Mock Moons.

62. Although the phenomena now to be referred to, belong more properly to the department of meteorology, to which a special section will be devoted, yet they cannot remain entirely unnoticed under the present head. The Aurora, improperly called northern light, as it appears at the south pole as well as the north, is the name of a luminous, often circular meteor, which sometimes appears in the vicinity of the magnetic pole of the earth, and

shines with an indescribable hue. It is only recently that astronomers have included the Aurora or polar light within the circle of their observations, and have found in almost every case, that simultaneously with the appearance of a northern light, there are certain phenomena about the south pole, sometimes consisting only of unusual disturbance of the magnetic needle. The eighteenth century was very prolific of northern lights, particularly the middle part of it; since 1820 they have also become much more frequent. *Pl.* 14, *fig.* 57, is a view of the remarkable Aurora Borealis which was seen at Christiania in Norway, at 6 o'clock in the evening of January 7, 1831. *Fig.* 58 represents an Aurora Australis or south polar light.

The *mock suns* and *mock moons*, or *parhelia* and *parselenia*, are a result of a peculiar reflection of the light of the sun, of the moon, and even of the brighter planets and fixed stars, upon particles of condensed vapor or ice crystals. When these halos are very much complicated about the sun and moon, they appear as if composed of many circles intersecting each other, of which one is generally horizontal, encircling the whole heavens. It is in this case that they form mock suns and mock moons. Generally, only two or four are seen; Hevelius, however, in 1660, saw six at once; sometimes they have comet-like trains. *Pl.* 14, *fig.* 59, exhibits a view of two such mock suns.

The Shooting Stars.

63. The *shooting stars* have been long and universally known, but it is only in recent times that their true character, their peculiarities, and the various circumstances under which they are perceived, have been matters of observation to astronomers and meteorologists. The periodical and abundant return of the shooting stars towards the middle of August and November, has in many places been diligently observed and investigated. We need only mention the efforts of Benzenberg, Brandes, Olbers, Bessel, Erman, Boguslawski, Quetelet, Feldt, Herrick, and Olmstead, to ascertain their direction, their height above the earth, and their velocity. The reasons for the now generally received hypothesis (of Alexander von Humboldt) are well known; his theory being that these luminous appearances are caused by innumerable small bodies revolving about the sun, which become visible by their combustion when entering the atmosphere of our earth. There are yet many difficulties in the way of the establishment of this theory, as also of the supposition of Biot, that these falling stars are the same bodies which, seen at a distance, form the zodiacal light.

Benzenberg and Brandes divide all shooting stars into three classes: 1, of the first and second magnitudes, similar to balls of fire, in which may be distinguished a ball with a luminous train; 2, of the first and second magnitudes, without the ball, and with a luminous path; 3, from the third to the sixth magnitudes, the last being telescopic, and only visible through a comet seeker.

The number of shooting stars is incredibly great. Humb[illegible]lt and Bon-

pland observed a magnificent fall of these bodies in 1799, and Brandes counted during one night, in a fifth part of the horizon, 480 shooting stars, from which he estimated the whole number, during the same time, at some thousands. Every one is familiar with the extraordinary showers which have appeared in America at various times. Benzenberg estimates the mean number appearing every night to be 30, 50, and even more. The train appearing behind the greater shooting stars deserves particular attention. Brandes has accurately observed and described the remarkable appearances presented by the last.

The height of these bodies is very various; some of them seem tolerably near the earth, while others are beyond the outer layers of the atmosphere, assuming this at 80 to 120 geographical miles from the surface of the earth.

The velocity of these meteors amounts, according to calculation based on observation, to between 16 and 32 miles in a second, thus reaching sometimes twice the velocity of the motion of our earth in space. Olbers has first shown how the shape of their orbit can be determined.

With regard to the substance of which the shooting stars are composed, nothing satisfactory is known.

The Antipodes of our Earth; the Habitableness of the Worlds of the Solar System.

64. The inhabitants of our earth may be considered, astronomically, under two points of view, namely, in respect to the degrees of latitude and longitude under which they live, and also in respect to the direction in which their shadow falls. By *Antipodes* is meant the inhabitants of that place on the earth's surface lying the distance of a complete diameter of the globe from some other place, as, for instance, Leipzig. The antipodes have an opposite geographical latitude, and a geographical longitude differing by 180 degrees; consequently, with the exception of those near the equator, an opposite time of year, and a time of day differing by 12 hours. Leipzig, for instance, has a north latitude of 51°, 20′, 20″, and a longitude 30°, 1′, 52″ east of Ferro; the antipodes of Leipzig, therefore, must dwell on a part of the earth's surface having a south latitude of 51°, 20′, 20″, and a longitude of 210°, 1′, 52″ east of Ferro. This point, however, lies in the great southern ocean, and, consequently, there are no proper antipodes to Leipzig.

Antæci (αντιοικοι) are the inhabitants of two places on the earth's surface, lying under the same meridian and at the same distance from the equator, but on opposite hemispheres. These have noon at the same time, but of course opposite seasons. At the two poles the antæci are also antipodes.

Periæci (περιοικοι) are those persons, who, living under the same latitude, differ in longitude by 180°. They have consequently the same seasons, but their days differ by twelve hours. At the equator, antipodes and periæci are synonymous.

65. Heteroscii (ἑτερο-σκιοι), or one-shadowed, are those inhabitants of the earth whose shadows among themselves always fall in the same direction; in an opposite direction, however, to the inhabitants of the opposite hemisphere. Consequently, the inhabitants of the temperate zones are one-shadowed; the shadows in the north temperate zone falling north, those in the south temperate zone, south.

The inhabitants of the frigid zones acquire the name of Periscii (περι-σκιοι), at the time during which the sun remaining above their horizon causes their shadows to move in a circle around them in the space of 24 hours.

Amphiscii (αμφι-σκιοι), or double-shadowed, are those inhabitants of the tropics who for one half of the year have their shadows directed towards the south, and for the other half towards the north. The cause of this lies in the fact of the latitude being less than the obliquity of the ecliptic. At any place whose latitude is, for instance, 17° north or south, a body will cast no shadow at all at noon of the day, when the declination of the sun is likewise 17° north or south. For this reason the Amphiscii are then termed Ascii (α-σκιοι), or shadowless. The inhabitants of the equatorial line itself will be shadowless on the 21st of March and 23d of September, since on these days the sun stands in the celestial equator. It has, consequently, then no declination, and the inhabitants of the line have no latitude.

66. It is not absolutely impossible that the sun may be habitable, as the black places which are seen in the middle of the sun's spots represent, perhaps, not the true nucleus of the sun, but only an obscure atmosphere similar to our own. The inhabitants of the sun, therefore, undazzled by the piercing light of the external solar surface or photosphere, and protected from its excessive heat, may live, ignorant, however, of the alternation of day and night. Neither can they know anything of seasons, since they are surrounded on all sides, and at all times, by the sources of heat and light. They can thus know nothing of the existence of the planets, moons, and comets; and can perceive the starry heavens in their beauty only through the openings which those violent agitations in the sun's photosphere sometimes produce.

67. Although *Mercury* receives an illumination from the sun almost seven times greater than that of our earth, the heat thus produced may be very greatly tempered by the numerous high mountains with their long shadows, the rapid alternation of the seasons, and the probably very rare atmosphere. In this manner an alleviation of temperature may result, which will without difficulty admit of this planet's being habitable.

Certain phenomena must take place in the climate and seasons of *Venus* which hardly admit of a comparison with ours. A day of Venus is very nearly equal to one of the earth, but it is very different with respect to the seasons, if we assume, as established, that the axis about which Venus rotates daily is inclined to its orbit at an angle of nearly 72°, and that thus the obliquity of her ecliptic is nearly three times that of the earth. It is well known that the seasons are determined by the obliquity of the ecliptic, and that, consequently, a much greater obliquity than that of our earth must necessarily involve a corresponding influence upon the temperature, and

especially upon the alternation of the seasons; it may, therefore, be assumed for Venus, that when the given circumstances take place, the torrid zone, whose inhabitants have the sun in their zenith, must cover a space of 144 degrees in breadth, while the breadth of this zone on our earth is but 47°. The frigid zone will lie at the two poles, extending 18 degrees towards the equator. The inhabitants of this zone will never see the sun in their zenith. In the temperate zone, occupying a space of 54 degrees from the frigid zone towards the equator, the inhabitants will not see the sun at all during one part of the year, and during another will have him in their zenith, thus resembling the inhabitants of both frigid and torrid zones on our earth. Hence it happens that the dwellers on Venus must experience such sudden alternations of season and climate as our imagination can hardly comprehend.

68. With respect to our moon, the curious arrangement of day and night, the want of an atmosphere similar to ours, of great bodies of water, and of seasons, as also the universal sterility and drought which seem to reign upon its surface, must undoubtedly exert an influence upon vegetable as well as animal life, of which we can have no adequate idea. The inhabitants of the moon, therefore, should such exist, must be very different from those of the earth. Even the view of the starry firmament from the moon must be very peculiar, since to its inhabitants the earth never sets. They who live in the centre of her visible disk always have the earth in the zenith, while those living on the border see us in their horizon. Sun, planets, and all other celestial objects, complete their paths in 29½ days, and thus rise and set, to the moon, every 14–15 days. The difference of seasons vanishes almost entirely on the moon, on account of the slight inclination of the equator to its orbit; and while the inhabitants of her equator have the sun always in the zenith, those of the poles see him always in the horizon. In the former part, therefore, there reigns an eternal summer; in the latter, an eternal winter; while intermediate between the two, a perpetual spring prevails. Days and nights are ever almost equal in length.

69. The physical condition of Mars most nearly resembles that of the earth; it is impossible, however, to offer any plausible hypothesis with regard to the asteroids, Vesta, Iris, Astræa, Juno, Ceres, and Pallas, as their distance and diminutive size conceal from us the peculiarities of their surface.

70. Since the various alternations of Jupiter follow each other with great rapidity, his hypothetical inhabitants must possess great quickness of mind and body. If their size bears any proportion to that of the planet, their height must be about 70 feet.

The inhabitants of *Saturn*, if any, must be entirely different from ourselves, and we have no cause to envy them. The nights of Saturn, as also the winters, last 15 years; there are total eclipses of the sun which last whole years; the sun appears ninety times less to them than to us; and, for years, total darkness and general torpidity, in all probability, reign supreme.

Whether the ring and the seven moons of Saturn, and whether Uranus

and Neptune with their moons, are habitable, are questions which must be left unanswered, as these planets, although little smaller than Saturn, are so remote as to render it impossible for us to ascertain the peculiarities of their physical condition by means of our telescopes.

As it is hardly supposable that all the planets and moons revolve about the sun as uninhabited worlds, and that only the earth has the prerogative of being peopled with any kind of created beings, so it seems not impossible, yea, rather entirely suited to the omnipotence of the Deity, to assume a certain habitableness of the comets. Shall these heavenly bodies, which are by far the most numerous of all the worlds belonging to our solar system, and in proportion to which the numbers of primary and secondary planets vanish away—shall these be entirely uninhabited, simply because man cannot comprehend of what sort the beings dwelling on the comets must be? In fact, it is a sentiment completely recognising the all-wise beneficence of the Creator, to presuppose that, upon those worlds wandering through such an immense extent of the heavens, certain beings may exist, as comfortable and happy as man, who so complacently considers himself as lord of the earth.

The Calendar in General; the Greek, Julian, Gregorian, Russo-Grecian, Jewish, Turkish, and French Republican Calendars in particular.

71. The Calendar belongs, from its nature and particular application, to the department of Chronology. Chronology, however, forms a part of astronomy, and, indeed, is a part of the greatest importance and most material value to the sciences, particularly the historical and political. For this reason it will not be superfluous to present here the most important features of the different calendars.

72. *Calendar* means partly the division of time employed by any people into definite years, months, &c., and partly the register of single days answering to a certain year of such a division. The word calendar is derived from the Latin calendæ (καλεω, *Lat.* calo, to call), by which name the Romans indicated the first day of every month, whose name and new moon were proclaimed by the priests, the calendar of any given year containing not only the religious and political festivals, but also the most important celestial events of that year. Among the latter are to be reckoned especially, the rise and setting of the sun and moon, the length of days and nights, the quarters of the moon, the eclipses of the sun and moon, the appearance of the planets, &c. We distinguish also, not only the calendars of different nations, but also special calendars, according to purport or object. Thus, for instance, we have astronomical, civic, centennial, economical, people, and states' calendars. We shall now hurry over the calendars of the most important nations in order.

Calendar of the Ancient Greeks.

73. The ancient Greeks assumed a lunar year of 354, later of 360 days, or 12 months of 30 days each, which they then sought to accommodate to the true solar year by intercalations. In honor of the Olympic games, the beginning of the year was placed at the first new moon after the summer solstice. Nevertheless, this did not always fall in July, as the Olympiads themselves consisted sometimes of 49, sometimes of 50 months. This Greek calendar was as complicated as the Macedono-Grecian calendar, introduced at a later period by Philip of Macedon, which commenced its year at the autumnal equinox, and which was employed for the names of the months, but not in their order, by the Greeks, Phœnicians, Babylonians, Medes, &c. The months of 30 days were called *full;* those of 29 days *deficient;* and each of these fell into three decades. By the gradual introduction of the Roman calendar among the nations subjected to that power, the Grecian fell into disuse.

Calendar of the Romans; the Julian Calendar.

74. The Roman calendar, improved by Numa Pompilius, was based on a lunar year, having one more day than a solar year. The first day of every month (the new moon) was called the calend, and besides this, two others were distinguished, the 18th before every new moon the *Ide*, and the 9th before the Ide the *None*. According to the reckoning of Numa, four months (Martius, Maius, Quintilis, and October) contained 31 days, and the rest 29 days, except February with 28, and the Macedonian month which was intercalated every two years with 22–23. There were therefore nones of seven and of nine days; with later arrangements the Ides also happened differently. The intermediate days were counted backwards from the Ides of the same, or the calends of the next month, as also from the nones of the same month. The Romans had besides periods of nine days, called *nundinæ*, which were indicated by the letters A to I. The *dies fasti* and *nefasti* were days of good and bad omen. Through the irregularity of distribution, and the then low state of astronomical science, it came to pass that about 46 years B. C. the Roman calendar varied about 59 days from the true day (that is, from the true place of the sun in the ecliptic). This induced Julius Cæsar, by the advice of the Alexandrian mathematician, Sosigenes, to adopt the *solar year* of 365 days, 6 hours, and so arrange the calendar that every year divisible without remainder by 4, should consist of 366 days, the rest consisting of 365. With respect to the subdivisions of the calendar, Julius Cæsar retained the old terms of calends, nones, and ides. This calendar is called the Julian.

Gregorian Calendar.

75. The Christians retained the astronomical arrangement of the Julian calendar in general, but established weeks of several days; January was the first month, December the last: January, March, May, July, August, October, and December, had 31 days, while April, June, September, and November, had 30. February had generally 28 days, except during the intercalary or leap year, when it had 29. At a later period, however, the length of the year was altered. Julius Cæsar had originally assumed too great a length for the year. This required, even in the time of Augustus, a correction of three days, and in 1581 the error had again amounted to ten days. The then reigning pope decreed on the 24th of February, 1581, an improvement of the calendar, by which ten days should be omitted from October of that year (counting 4, 10, 15 October), and in four centuries three leap years should be omitted, by which the years 1700, 1800, 1900, 2100, &c., were not leap years. This Gregorian calendar was soon introduced into all Catholic countries, while the Protestants retained the old system until 1699. In the year 1700, in February of the new improved calendar of the German Protestants, ten days were omitted, so that March 1st came immediately after February 18th. With respect to Easter, which in the Gregorian calendar of the Catholics was counted after the Epact, the Protestants assumed a purely astronomical mode of calculation, so that this always came on the Sunday after the first full moon succeeding the vernal equinox (thus between March 22 and April 25). This improved calendar agreed for the most part with the Gregorian, but with respect to the different determinations of Easter, cases soon occurred in which one calculation made Saturday, and the other Sunday, the day which determined the celebration of Easter on the Sunday following. According to the latter calculation, therefore, this festival would happen eight days later than as determined by the former, which produced great confusion among those Catholics and Protestants living near each other. When, in 1778, this was about occurring, Frederick II. of Prussia succeeded in persuading the Protestants of Germany to adopt the determination of Easter by the Epact. To this arrangement the other Protestant states of Europe have also conformed.

It will be necessary to add a few explanations of certain expressions which are connected with the determination of single days and festivals in our calendar. The determination of Sundays and week days depends upon the *Sunday* or *Dominical Letter*, and the *Solar Cycle*. The Sunday letter is that which falls upon the first Sunday, when we call the first day of the year A, and count from A to G. Should the year be leap year, count the Sundays after February 24th one further. It is necessary to know these letters to understand the construction of the perpetual calendar.

The number of years after which the same week days fall upon the same date again, is determined by the solar cycle. Were there no leap years, then, as the date annually advances one on the days of the week, the same

date would fall every seven years upon the same day of the week; since, however, every fourth year is leap year this coincidence takes place every 28 years, which form one solar cycle, the series beginning the ninth year B.C.; thus, in 1847, the solar cycle is VIII., that is, it is the eighth year of a sun cycle in the nineteenth century.

The *Lunar Cycle*, the *golden number*, and the *Epacts*, serve to determine the phases of the moon, and occurrence of Easter. The lunar cycle is the series of years after which the new and full moons again fall upon the same day of the year. This cycle amounts to 19 years of $365\frac{1}{4}$ days, and the number of any year indicating its place in the cycle, is called the *golden number*. This cycle was discovered by Meton, 430 B.C., and the golden number is the remainder after adding one to the number of years, and dividing by 19. The quotient indicates the number of lunar cycles which have elapsed since A.D. up to the given time. Should the golden number be one, then the new moon falls on Jan. 1. For the determination of the new moon of any other years, the *Epacts* are employed, or the number which, for every year, determines the age of the moon on New Year's day, or gives the number of days by which the last new moon of the previous year preceded New Year's day. Should the new moon fall on Jan. 1, then the Epact = 0.

As the lunar year is 10 days, 15 hours, 11 minutes, 25 seconds, or, in round numbers, 11 days shorter than the solar, it follows that the Epacts increase annually by 11; so that if, in one year, the Epact was 23, in the following it would be 3, as the series commences with 1 after 30. The passage from the last year of a lunar cycle to the first of the following, amounts, not to 11, but to 12 days, and is called the *leap of the Epacts*. This intercalary day is necessary, from the fact that the lunar year is not quite 11 days shorter than the solar year. For the year 1847 the golden number is 5, and the Epact 14. Knowing the Epacts, it is possible in a perpetual calendar to determine immediately every day upon which new moon falls. Thus, for the Epact 14, of 1847, the first new moon falls on the 16th of January; nevertheless, small errors cannot always be avoided, as, for instance, is the case in the year mentioned, when the first new moon actually occurs early on the 17th January, at 1 hour, 34 minutes. After the occurrence of the new moon, we can readily determine the remaining phases of the moon.

RUSSO-GRECIAN CALENDAR.

76. The calendar of the Russians and Greeks has, in respect to the months, weeks, main festivals, &c., the same arrangement as the Gregorian calendar; nevertheless, these nations have retained the Julian in its essential features, that is, with respect to Easter and the festivals dependent upon it. They are, therefore, about 13 days behind the Gregorian date now, and will, in 1900, be 14 days; so that in the present century, for example, when they have March 1st according to their calendar, it will be March 13th

according to the Gregorian. The Greeks and Russians have, thus, the *old style* reckoning; the other Christians, the *new style*.

JEWISH CALENDAR.

77. The Jewish years are lunar years, counted from Oct. 7th of 3761 B.C. The Jews have, according to the improvement of Rabbi Hillel Hanaffi, a cycle of 19 years, among which 12 are common, and 7 intercalary years. One of the former has 354 days, 21 hours, 48 minutes; one of the latter, 383 days, 21 hours, 48 minutes. To satisfy the priestly arrangement there are six different years, namely, three *common years* of 12 months each, the short year having 353, the mean year 354, and the long year 355 days; and three *intercalary* or *leap years*, of 13 months each, the short year having 383, the mean 384, and the long 385 days. The beginning of the year can fall neither on Sunday, Wednesday, nor Friday. The months of the civil year are in order as follows: TISCHRI, MACHESVAN, KISLEV, TEBETH, SCHEWAT, ADAR, W'ADAR (intercalary month), NISAN, JJAR, SIVAN, THAMUZ, AB, and ELUL. The religious year begins with the month NISAN, in which the principal festival, the *Passover* (Easter), falls, and, indeed, always on the 15th NISAN. This Passover, which can never fall on a Monday, Wednesday, or Friday, is of the greatest importance in the arrangement of the Jewish calendar, and generally occurs in our Passion week. In conclusion, it may be stated, that our Saturday is kept under the name of Sabbath (day of rest) just as Sunday is with us.

TURKISH CALENDAR.

78. The Turks and almost all adherents of Mohammedanism count their years from *Hedschra*, or *Hegira* (July 15, 622 A.D.). They have a cycle of 30 years, each consisting of 354 days, except 11, which are leap years of 355 days. Their year, whose mean length amounts to 354 days, 8 hours, 48 minutes, is divided into 12 months of 30 and 29 days: MOHAREM, SEPHER, RABI EL AUWAL, RABI EL ACHAR, DSJOMMADA EL AUWAL, DSJOMMADA EL ACHAR, RADSJEB, SCHABAN, RAMADAN, SCHAUWAL, DSULKADE, and SULHADSJE. In the leap year, the last month, SULHADSJE, instead of 29, has 30 days, the latter being the intercalary day. The festivals of the Turkish calendar occur unchangeably on the same day of the month.

CALENDAR OF THE FRENCH REPUBLIC.

79. By a decree of the French National Convention of Oct. 5th, 1793, a new reckoning of time was adopted, dating from September 22d, 1792, on which day, previously fixed upon, the establishment of the Republic was decreed. As this was also the date of the equinox (at $9^h\ 18'\ 13''$ of the morning) there was an allusion given to equality both of days and rights.

The following years were also to begin with the midnight preceding the true autumnal equinox. This new French year was divided into 12 months of 30 days, and to complete the number of days, five, or in leap year six supplementary days (*jours complémentaires*), were added. Instead of weeks, the months were divided into three decades of 10 days each. These ten days were called *Primidi, Duodi, Tridi, Quartidi, Quintidi, Sextidi, Septidi, Octidi, Nonidi, and Decadi.* The nomenclature of the months was derived from the characteristics of the seasons, as follows:—

For Autumn: Vendemiaire, or vintage month (October); *Brumaire,* or cloud month (November); *Frimaire,* or frost month (December).

For Winter: Nivôse, or snow month (January); *Ventôse,* or wind month (February); *Pluviôse,* or rain month (March).

For Spring: Germinal, or growth month (April); *Floréal,* or bloom month (May); *Prairéal,* or meadow month (June).

For Summer: Messidor, or harvest month (July); *Thermidor,* or heat month (August); *Fructidor,* or fruit month (September).

The additional days are attached to this last month, and have the following appellations:—1*st, Fête du génie;* 2*d, Fête du travail;* 3*d, Fête des actions;* 4*th, Fête des recompenses;* 5*th, Fête de l'opinion.*

In addition to what has already been said, every day of the year had its especial name, which, instead of being taken from some saint, was derived from objects of agriculture appropriate to the time on which the days fell. This calendar, however, lasted only 12 years, for Napoleon abolished it by a Senate decree of September 9, 1805.

ASTRONOMICAL INSTRUMENTS; OBSERVATORIES.

80. *Astronomical instruments* embrace all the apparatus which the practical astronomer needs in his observations of celestial phenomena, to impart to them that accuracy and certainty so necessary as the basis of delicate calculations, as also to find objects in the heavens invisible to the naked eye. Astronomical instruments have two purposes: the one is to afford a clear understanding of those objects and phenomena of the heavens, which, on account of their distance or minuteness, are either imperfectly or not at all visible to the naked eye; the other purpose is the accurate measurement of various angles and spaces. The following may therefore be considered as the most important astronomical instruments:—Transit Instrument, Equatorial, Refractor, Meridian Circle, Universal Instrument, Comet Seeker, Heliometer, Simple Circle, Theodolite, Multiplication Circle, Reflecting Sextant, Barometer, Thermometer, Pendulum Clock, Chronometer, &c. Of the more ancient instruments, only the Zenith Sector and Mural Quadrant are retained at the present day; all the rest, as, for example, the Octants, Quadrants, Telescopes without tubes, &c., are consigned to deserved oblivion.

The following are the names of some artists distinguished for the excellence of the astronomical instruments constructed by them. Those

marked + are deceased Baumann (in Stuttgart); Breithaupt (in Cassel); Cauchoix (in Paris); Dollond+ (in London); Douve+ (in Berlin); Emery+, Ertel (in Munich); Fraunhofer+ (in Munich); W. Herschel+, Jürgensen (in Copenhagen); Kessels (in Altona); Lerebours (in Paris); Merz and Mahler (in Munich); Oertling and Pistor (in Berlin); Plössl (in Vienna); Ramsden+ (in London); Repsold, sen.,+ and Repsold Bro's (in Hamburg); Reichenbach+ (in Munich); Lord Rosse (in Ireland); Troughton+ (in London); Voigtländer (in Vienna); and others.

THE TELESCOPE; ITS DIFFERENT CONSTRUCTIONS.

The Dorpat Refractor.

81. The Telescope is that optical instrument which represents distant objects more distinctly and of larger size than they appear to the naked eye. There are two principal kinds of telescopes, dioptric or *refractors*, and catoptric (or more properly catadioptric) or *reflectors*. In refractors, observations are conducted by means of glasses alone, as, for example, the eye glass and object glass; in reflectors a concave mirror is used instead of the object glass. Both were invented in the sixteenth and seventeenth centuries; the refractor in 1590, by Jansen of Middleburg, and the reflector in 1644, by Mersenne.

Refractors consist of a cylindrical tube at whose two extremities are placed the lenses employed. The lens receiving the rays of light from the object, is called the *object glass* or *objective*. The one through which the image produced is seen by the eye is called the *eye-glass* or *ocular*. Eye-glasses are *simple* when but one lens is used, *compound* when several lenses are combined together. Besides the *magnifying power* of the telescope, reference must be had to the *diameter of the field of vision*, the *illumination* or *amount of light*, and the degree of distinctness of vision.

There are three kinds of refracting telescopes; the *astronomical*, invented by Kepler; the *terrestrial*, invented by De Rheita, 1665; and the *Galilean*. The astronomical telescope is formed by the combination of two convex lenses; the one, the eye-glass, can be made to approach to or recede from the object glass. This form of telescope, although it represents objects inverted, exhibits them very clearly and much magnified; having also a large field, it is on this account principally used by astronomers.

The second kind, or the terrestrial telescope, is a combination of four convex lenses; three of them, fixed immovably in one tube, can be made to vary their position with respect to the fourth—the object glass. This telescope, which exhibits objects erect, may be considered as a combination of two astronomical telescopes, of which the one represents the inverted image of the other again inverted, consequently actually erect. Nevertheless, it is more advantageous to furnish the terrestrial telescope with four eye-glasses, as is generally done. The eye-glass nearest the eye thus

obtains (as also happens in astronomical telescopes) a second eye-glass, viz. the so called *field glass*, for the purpose of enlarging the field of vision.

The Galilean telescope is the simplest of all, consisting of but two lenses—a convex object glass, and a concave eye-glass; this represents objects erect. It has, however, the inconvenience of possessing a very small field of vision, especially when the eye is not exceedingly near the eye-glass.

The common telescopes, however, do not exhibit any very great degree of clearness of vision, as all images produced by them are surrounded by a colored border, and a considerable magnifying power can only be obtained with a length of 5 or 6 feet. Dollond remedied this defect in 1757 by his *achromatic* (colorless) object glasses. An achromatic object glass consists of two highly polished lenses, combined so as to be everywhere in absolute contact, the one convex, made of crown glass, the other concave, of flint glass. The two kinds of glass have different refractive powers, so that chromatic aberration is reduced almost to a minimum. Telescopes with such object glasses, and of a moderate length, afford with a considerable magnifying power, and great brightness and distinctness, images almost entirely without colored borders. Very large instruments of this kind are known pre-eminently as refractors. The preparation of the glass required, so as to be everywhere uniform and without bubbles and streaks, presented great difficulties, until they were surmounted by Fraunhofer and Uzschneider.

On account of the differences in eyes, and the varying distances of objects, a special adjustment is required for the eye-piece. In small telescopes this is done by moving the tube in or out with the hand alone; in larger instruments a screw adjustment is necessary, by which the eye-piece (ocular) can be moved almost insensibly. The larger telescopes are set up either on a three-legged frame or upon a pyramidal support, and their motions are either horizontal and vertical, or for astronomical purposes parallactic, i. e. applicable to any direction.

As an illustration of the mode of constructing and setting up a great telescope, we have selected the giant achromatic refractor constructed by Fraunhofer for the observatory of Dorpat. The instrument arrived there November 10th, 1824, and the first glance was directed by Struve, six days afterwards, towards the moon and some double stars. The principal parts of the instrument (*pl.* 15, *fig.* 2) are—1, the stand A, A, A; 2, the axes F and I, with their circles *d* and *k*; 3, the telescope B, B; 4, the counterpoises E, E′, K, M, H; 5, the clock-work, *e*, *f*, *g*, with the weights. The stand is parallactic; upon it rests the hour axis F, parallel to the polar axis, with its hour circle, *d*, at the lower end. A second axis, I, stands perpendicular to the first, and consequently in a rotation of the instrument about the latter, describes the plane of the equator. At one end of this second axis is the declination circle, *k*; at the other, the bed of the wooden tube, B, B, of the telescope, with brass caps at the two ends for the lenses, and the finder, D, D, at the upper side. The counterpoises are five; two, E and E′

on the telescope, to balance the greater weight of the anterior half of the instrument; two, M and K, in the direction of the declination axis; and one, H, to diminish the friction of the hour axis. The clockwork, *e*, *f*, *g*, lies on the left side of the hour circle, *d*, and acts upon an endless screw which catches in it, and even without the clock-work, may be employed to produce a gentle motion about the hour circle. A second micrometer screw, *i*, is attached to the declination circle, *k*, to produce the adjustment in the declination. In a perpendicular position of the telescope, the height of the whole instrument amounts to 16 Paris feet, and the weight to about 4000 Russian pounds. The steel hour axis, 39 inches in length, carries the hour circle of 13 inches diameter, with a graduation on silver on its lower face; each of the two verniers reads to within 4 seconds of time. The declination circle is 20 inches in diameter, and its motion is regulated by a clamp and micrometer screw. The circle itself has a graduation on silver, and the vernier reads to 10″. The length of the telescope is $13\frac{7}{12}$ Paris feet, with a diameter of 10 inches at the upper end, and $7\frac{3}{4}$ at the lower. The object glass has a free aperture of 9 inches, and a focal length of 160. The four free oculars of 1420, 210, 320, and 480 magnifying power, as also the various micrometer apparatus with 14 oculars, can be screwed into the end of the draw tube. The aperture of the objective of 30 inch focus, belonging to the brass finder, amounts to 29 Paris lines. This finder has two oculars of 18 and 26 magnifying power. The clock-work intended to give to the telescope a motion on its hour axis, uniform with that of the fixed stars, and represented on a larger scale in *fig.* 20, consists of two principal parts; the clock proper and the wheelwork connecting this with the hour circle. Both are fastened to the bearing piece at the lower end of the hour axis. This wheel consists of an axis to which are attached the two wheels *d* and *e*; on *d* the disk *f* (the latter is omitted on the figure) is screwed; a smaller disk, *g*, is attached anteriorly by the screw *h*. An endless thread with the weights runs over *f* and *g*. At *i* is seen the spring and trigger catching in the teeth of the disk *g*; *d* is in connexion with the little wheel *k*; *l* and *m* are apertures. The clock drives an axle, *n*, with a double-motioned endless screw, working in the wheel, *e*. The motion of the clock is regulated by a centrifugal balance wheel which is connected with the weights by means of three wheels and pinions; *p* and *q* are cog-wheels, *r* a crown wheel acting on the pinion of the perpendicular axis *t*. The centrifugal balance wheel works within the box *u*; the parts, *w*, *x*, *y*, *z*, serve to regulate the motion of the clock, which, as well as that of the friction weight, continues to move more than an hour. Both the clock and the friction weight may be removed without disturbing the motion of the telescope. The micrometer arrangements inside the telescope are adjusted with great accuracy, but their enumeration and explanation here would carry us too far out of our way.

The value of this great refractor consists in its optical completeness, in the great accuracy of its adjustments, in the regularity of rotation about the hour axis by means of the clock, as well as in the perfectly unalterable micrometrical apparatus. In defining power and intensity of illumination,

this refractor leaves all known reflecting telescopes far behind. Struve saw the multiple star τ Orion certainly 16-fold, while Schröter with his 25 foot refractor only saw it 12-fold; the little companion of the star β Orion (Rigel) was seen through the Dorpat refractor very distinctly just before sunset; and even ω^2 Leonis, one of the most difficult double stars, in this instrument, was recognised without any difficulty as a double star. In conclusion, it remains to be mentioned, that this telescope is placed in a building specially arranged for rotation. The cost of the instrument amounted to 10,500 florins ($5000).

More recently the observatory at Pulkowa has received a somewhat larger refractor from Munich, whose object glass has an aperture of $14\frac{9}{10}$ Paris inches. The new Berlin observatory also possesses a large refractor of remarkable excellence from this same celebrated manufactory at Munich. The observatories of Cambridge, Washington, and Cincinnati, likewise possess refractors of great power.

When in use, the telescope is directed to the object to be investigated, whose motion is followed by changing the position of the instrument. If the telescope be arranged as in the Dorpat refractor, all the clamps are to be loosened, the object found with the seeker, and the instrument then fixed; upon which, by means of the clock-work, it is moved in such a manner as always to have the object in the field of vision.

The Reflecting Telescope; Herschel's Giant Telescope.

82. Catoptric (catadioptric) telescopes, commonly called reflectors, form the second grand division of these instruments.

The reflector is a telescope which, instead of an object glass, has two mirrors, an objective and a reflecting mirror. Newton constructed the first reflecting telescope of the form now bearing his name. This consists of a hollow cylinder, so placed upon a frame as to be readily directed to any point of the heavens. The one end of this cylinder is closed by a spherically concave metallic mirror or speculum, whose focus lies in the common axis of the cylinder and mirror. At a little distance from the focus of the speculum is placed a plane mirror inclined to the axis of the cylinder at an angle of 45°. A beam of light impinging upon the concave mirror, is reflected in a cone upon the small plane mirror, and thence into the ocular placed in the side of the instrument and at right angles to it. This arrangement, therefore, represents objects inverted, unless, as in the terrestrial telescope, erecting lenses be placed in the eye-piece. After Newton's death another form, the *Gregorian*, with the smaller reflector concave, came into use; this represented objects erect. A third kind, the Cassegrainian, was also introduced. This last has the small anterior reflector convex instead of plane, as in the Newtonian, or of concave, as in the Gregorian; objects are represented in it inverted.

Herschel improved the Newtonian telescope by omitting the small reflector, fixing the large concave speculum at a slight angle to the axis.

The focus consequently was formed at the anterior edge of the instrument, where it was received by the ocular. The observer sat directly in front of the open tube looking through the ocular.

In this manner Herschel constructed his 20 and 30 foot telescopes; the 20 foot with a speculum of 10 inches diameter. A seven foot reflector finished by Herschel in 1780 was of great excellence; with it he discovered Uranus on the 18th of March, 1781. The magnifying powers were 230, 460, and 930; but to his greater reflector Herschel could apply powers of 500–2000, without overtasking them for strongly illuminated objects. The giant 40 foot telescope completed in 1789, is represented in *pl.* 15, *fig.* 1. The tube, DD, constructed of sheet-iron, was 40 feet long, 4 feet 10 inches in diameter, and the whole telescope weighed about 5100 pounds; the great speculum alone weighed 2148 pounds. The magnifying powers of the instrument were, for the planets, 250 and 500; for the fixed stars, 1000–6400. The distinctness of the objects seen is said to have been astonishingly great. The cost of the whole apparatus amounted to about £2000 sterling. During observations with this colossal instrument, Herschel sat at the side of the tube at its upper end, in a frame H, fixed to the ladders, G, G, which accompanied the tube in its movements. He thus looked into the instrument, with his back to the star, and examined this latter directly with the eye-glass. Unfortunately the mirror, during a single damp night, lost its polish, and the whole instrument in a few years after its construction was entirely useless. The figure gives, without the necessity of further explanation, an idea of the strong scaffolding between which the telescope could be moved in a perpendicular direction by means of several ropes, AE, FE; the horizontal motion of the whole apparatus, scaffolding and tube, was produced by a rotation by means of rollers running upon the periphery of a horizontal circular railway, ABAB. Around and above the whole was built a round tower with a revolving roof, whose opening could be brought towards the part of the heavens to be observed. More recently Lord Rosse has constructed a gigantic telescope, more than 12 feet longer than that of Herschel, having a speculum of 6 feet in diameter.

The Mural Quadrant.

83. As long as astronomical observations did not possess that degree of accuracy now exhibited, the *mural quadrant* was, of all instruments used in measuring altitudes, the most useful. *Pl.* 15, *fig.* 19, represents the celebrated mural quadrant of Tycho. This had a radius, DC, of eight feet, by means of which, aided by a vernier, E, very small arcs could be read off on the limb CC. The iron grating, DCC, which formed the body of the quadrant, was fastened to a wall, GAA, placed in the meridian, and the rule DD, with the telescope, moved up and down on this grating. In this manner it was possible to observe not only the passage of the meridian by a star, but also its altitude or zenith distance. The depending plumb-line, DA, served to fix the quadrant in its proper position in the vertical plane.

Movable quadrants were also used; and the constructions of Dollond and Troughton (*fig.* 18) were the most convenient. The principal part consisted of the quarter circle, EF, and two attached radii, IE and IF, perpendicular to each other, all of metal. Through the centre of gravity of the movable part of the whole instrument, passed a cylindrical tube, fastened to the quadrant IFKE, and including the axis of rotation; this gave off a vertical post resting on a solid base, AAD, adjustable in a horizontal plane by the screws B, B, B. This post was received in such a manner into a tube, C, fastened to the base, as always, in rotation, to preserve a vertical position. The body of the quadrant was united in such a manner to this part containing the axis of rotation, as to have its plane constantly vertical, and parallel to the axis of rotation. Upon the part containing the axis of rotation was attached the azimuth circle, DD′, graduated to ten minutes, readable to ten seconds by means of a vernier. The quadrant, divided to five minutes, was readable to single seconds by the micrometer, G. The quadrant, with the movable telescope, KL, was so placed that one of the above mentioned metal radii was rendered perfectly horizontal by means of an attached level. H was a lens for reading off the graduation. Finally, as another means of determining the vertical position, a plumb-line was suspended in the above mentioned tube of the axis of rotation, whose proper position was given by four microscopes. K was the position occupied by the observer when looking at the stars through the telescope KL.

The Transit Instrument, or Meridian Telescope.

84. The transit instrument, one of the most important instruments of practical astronomy, was invented by Roemer in 1706. It is intended to obtain with greater accuracy the right ascension of a star, and consequently the solar time. It consists (*pl.* 15, *fig.* 13) of an astronomical telescope, FD, fastened at right angles to a horizontal axis, B, and movable up and down in such a manner that the plane described always lies in the plane of the meridian of the place of observation. For the sake of the greatest possible firmness, the pillars, AA, upon which the two pivots of the horizontal axes rest, must be fixed separately, each one consisting of a single block of granite, and going deep into the earth, without any communication with the masonry of the building.

Portable transit instruments have also been constructed, differing, however, from the fixed only in their smaller size and their being adjustable to any point. *Pl.* 15, *fig.* 22, represents such a portable transit instrument. Although the transit instrument is not usually employed to obtain the meridian altitude of a star, yet for the approximate attainment of this end, a circle graduated to numbers is fastened to one side of the instrument in a vertical plane, as at I in *fig.* 13, and D, *fig.* 22.

In the fixed, heavy transit instruments, it is absolutely necessary, for the purpose of lessening the friction, and the wearing of the pivots, to diminish

as much as possible the weight resting on the beds of the horizontal axis: this is done by counterpoises, as seen at H, H (*fig.* 13), L, L (*fig.* 11), and G, G (*fig.* 3). These act on one arm of levers whose fulcra are supported by the solid parts of the instrument, the other arms carrying stirrups through which the axis is received, so that this latter just touches the socket in which its pivots turn.

In the interior of the telescope, at the focus of the eye-glass, is the wire plate of fine threads of wire or other material, of which two are horizontal and an indefinite number vertical. The object here is to give greater precision to observation, by dividing the field of view into a certain number of subdivisions. This wire plate can be so moved as to be brought accurately into focus, and there regulated; to render it visible, however, it must be illuminated from without. This is done by making one half of the axis hollow, and reflecting the light of a lamp through this cavity into a hole in the side of the tube of the telescope. By this means, the cross lines are dark on a light ground. The illumination employed by Fraunhofer is, however, much more convenient; this is applied between the eye of the observer and the focus. Here the whole field of the telescope remains dark, the cross lines alone being illuminated, so that object and cross lines can be distinctly seen at the same time. As much depends upon the perfectly horizontal position of the axis of the instrument, it becomes necessary to apply frequently a test of this, which is done by a tubular level placed above or below, as in *pl.* 15, *fig.* 13, L. In the portable transit instrument (*pl.* 15, *fig.* 22), the stand, AABBCC, consists of a cast iron crown, upon which the two parts for the axis are immovably fastened. The horizontal position of the instrument is controlled in one direction by a level placed upon the axis; in the other, by a level, F, placed upon the declination circle, D.

The rectification of an astronomical instrument, or the determination of its faults, must precede its use. Three principal errors may attach to the transit instrument: in the first place, it will almost always deviate from the meridian, that is, it will have a small eastern or western azimuth; in the second place, it will almost always be inclined at a small angle to the plane of the horizon, which is determined by the dependent level, L (*fig.* 13); thirdly, the optical axis of the telescope will deviate at a slight angle from the line drawn perpendicular to the axis of rotation: this last error is called the *error of collimation*. These three errors must be ascertained and rectified, partly mechanically, and partly by calculation; as also the four errors to which the diaphragm or wire plate is generally subject.

Fig. 25 is a side, and *fig.* 31 a back view of a small transit instrument constructed by Repsold for the observatory of St. Petersburgh. A are the pillars of the axis G, fastened to a granite block: the pieces in which the pivots of the axis turn, are shown more in detail by *figs.* 26 and 27. E is the declination circle with its vernier, F, and the level, I, situated above the axis. The telescope, BD, is only partly given. At D is the adjusting screw for the ocular, given more in detail by *figs.* 28 and 29. Its micrometer arrangement is shown in *fig.* 30, where the wire plate is moved in the box, *b*, by the screw *a*. *Fig.* 32 is one of two supports which stand in excava-

tions of the two pillars, A, carrying friction rollers above, upon which the axis G rests. *Fig.* 34 is a handle for directing the telescope.

Circular Instruments.

85. As the irregularities produced by changes of temperature, eccentricity, specific gravity, &c., are greater in a part of a circle than in an entire one, it follows that even the most perfect quadrants do not afford the greatest possible degree of accuracy; for this reason full circles were introduced, now used almost exclusively in the determination of altitudes, and to which the remarkable precision of the astronomical observations of the present day is owing. To the circular instruments belong: 1, the *repeating circle*; 2, the *simple circle*; 3, the *meridian circle*; and 4, the *theodolite*.

86. The *repeating circle* of Dollond (*fig.* 14), intended for observations out of the meridian, rests upon a tripod stand, AA, which, by means of the adjusting screws, and the level F, can be made perfectly level. Upon this rests the horizontal circle, B, on which the direction of the alidade, H, can be accurately read off by means of four verniers provided with lenses: of these, only D and E are visible. The alidade H, which supports the four posts, I, I, I, I, of the full circle, is adjusted by the telescope T. The posts carry the beds for the horizontal axis of rotation of the two circles, O and L, and the principal telescope, M, whose horizontal position is regulated by the level attached to the strips K, K. The main telescope, M, has an adjustable ocular, provided with a micrometer arrangement. This telescope is fastened to the vernier carrier, PQ, which then determines altitudes in the fixed circle, O. The manner in which the repetition or multiplication is effected will be understood by referring to what has been said in the part of the work relating to measuring instruments (*p.* 65). We will here only remark, that for this purpose the vernier carrier, PQ, is fastened to the axis by clamps, which can be loosened in repeating. Reichenbach has very much improved the repeating circle; nevertheless, as there are always defects in the instrument, attention is now turned almost exclusively to *simple fixed* circles.

The Meridian Circles.

87. The most prominent and costly instrument of modern practica- astronomy, is incontestably the *meridian circle*, another kind of full circle, used to determine the altitudes of stars. This instrument serves not only to observe in the most accurate manner the culmination of the stars (as in the transit instrument), but also their zenith or polar distance. The entire instrument must therefore be set up in such a manner that its horizontal axis of rotation shall lie accurately in an east and west direction. The planes also of the two circles perpendicular to this axis, as well as the optical axis of the telescope, must be in the plane of the meridian. The meridian circle has much the same construction of the individual parts that is found

in the transit instrument, as also the same errors and corrections. To the latter is to be added the verification by the observed altitude or polar distance of the star. The best meridian circles of an earlier date are those of Ramsden (particularly the one at Palermo) and of Troughton (at Leipzig). Perhaps the most perfect of more modern construction are those made by Reichenbach, and especially by the brothers Repsold in Hamburg.

In the meridian circle erected at the Hamburg observatory in 1836, its constructors, A. and G. Repsold, sought to solve the problem of avoiding every error arising from flexion, by the greatest equality and counterbalancing of the individual parts. For this reason the instrument is symmetrical in all its parts, the axis, BB (*pl.* 15, *fig.* 11), being bored within as well as without; two circles, F, F, of equal weight, with the accompanying microscope carriers, burden equally the axis, BB, and require equally heavy counterpoises, L, L, on both sides. To avoid a possible alteration of the axis, the attachment is very near the telescope, and a corresponding counterpoise on the other side restores the equilibrium of the whole. The circles are of cast brass, 3 feet 2 inches (French) in diameter, graduated on silver for every 2 minutes. These circles have four verniers, by which the angles can be read off to single seconds by lenses, R, R, fastened to the microscope carrier, FF. The massive centre, B (*pl.* 15, *fig.* 12), of this microscope carrier, itself composed of hollow tubes for the purpose of measuring absolute heights, is fitted to the axis in such a manner as to move freely without great friction in the boxes. The telescope (*fig.* 11), CE, with a Fraunhofer object glass, C, of 5 feet focus, consists of two equally heavy conical tubes, CB, BE, of hammered brass, which, firmly united to the axis BB, admit of no bending. The illumination of the cross lines is effected through the hollow axis by a mirror in the tube, a lamp being placed in one of the tubes running out in the prolongation of the axis. The obscuration, as also the regulation of the illumination, is quickly effected by a wedge of colored glass worked by a rack. The beds of the axis, entirely independent of the other parts of the instrument, are screwed fast to blocks of brass in the pillars, A, A′, behind which are the brass plates which support the posts, M, K, for the counterpoises L, L.

88. The meridian circle at the central observatory of Pulkowa (St. Petersburg), also erected by the brothers Repsold, is very similar to the preceding, though on a larger scale. *Fig.* 3, *pl.* 15, represents it in perspective. The two pillars, A and A′, are of grey granite, $7\frac{3}{5}$ feet high, and 18 inches broad each way at the upper end. The telescope, CB, has a focal length of $83\frac{1}{3}$ inches, $5\frac{4}{5}$ inch aperture of objective, and possesses magnifying powers of 170, 238, and 245. The wire plate in the focus at C, consists of two horizontal and nine vertical wires. Each of the two circles, BKEK and BK′E′, has a diameter of 48 inches, and is divided on silver to two minutes. For the counterbalancing, the counterpoises, G and G′, are attached to special metal posts, I, H and I′, H′. The whole instrument can be raised at F and F′. The level N rests on the cross piece M. *Fig.* 4 exhibits the microscope carrier on a larger scale. This consists of the hoop EE; the four microscopes themselves are at K, K, K, K; LL and

L'L' are the two levels, whose end views are given immediately to the left hand, with their mode of attachment; *d*, *d*, *d*, *d*, *e*, *e*, *e*, *e*, are the spokes; *c*, *c* and T, T are hollow tubes. *Fig.* 5^a is a front view of the eye-piece of the telescope, CB (*fig.* 3); the letters *a*, *b*, *c*, *f*, *g*, *h*, in *figs.* 5^a, 5^b, indicate the separate parts of the wire micrometer, and *d* the pin for its adjustment; *c* (*fig.* 5^b) is the separate tube of the ocular. *Fig.* 6 shows the construction of one of the four microscopes, K, attached to the microscope carrier; *figs.* 7, 8, 9, and 10, represent particular parts of the micrometer arrangement. *Fig.* 7 is the inner, *fig.* 8 the outer plate; *fig.* 9 the spindle of the micrometer screw *h*; and *fig.* 10 the external view of the whole micrometer arrangement from above.

The Equatorial.

89. The *Equatorial* is an instrument by means of which, not only the declination, but also the difference of right ascension of a star and the zenith can be ascertained. Some idea of the instrument may be obtained by supposing an altitude circle so arranged, that the axis of rotation, previously vertical or perpendicular to the plane of the horizon, shall be perpendicular to the equator; in other words, that this axis placed in the meridian shall form an angle with the horizon equal to the height of the pole at the place of observation. Thus, in the altitude and azimuth instrument, the axis of rotation moves towards the zenith; in the equatorial, towards the pole of the equator. Its axis thus becomes parallel to that of the earth, and the azimuth circle of the simple circle becomes an hour circle, and the altitude circle a circle of declination. This instrument, when very accurately constructed and adjusted, possesses the exceedingly important advantage of giving, out of the meridian, the same determinations which the meridian circle affords at the moment of culmination alone.

The equatorial, as at present constructed, rests upon a prismatic stand. In the smaller portable instruments, however, the middle of the polar axis, I (*fig.* 15, which represents the one constructed by Repsold for the Hamburg observatory), rests upon a vertical brass pillar, A, with three feet; LMN is the hour circle, figured more intelligibly in *fig.* 17, with its micrometer arrangement, N, and the counterpoise, K. GHF (*fig.* 15) is the declination circle; C, D, K, the counterpoises for diminishing the friction; and OP the movable telescope. A very minute division of the hour circle is, strictly speaking, not necessary, as the exact determination of the right ascension is obtained in another manner. *Fig.* 16 shows the external and internal construction of the axis, EH, of the declination circle, GHF. In a well constructed equatorial—1, the axis of rotation must lie in the plane of the meridian, and 2, must form an angle with the horizon equal to the altitude of the pole at the place; 3, the plane of the declination circle must be parallel both to the axis of rotation and to the optical axis of the telescope.

The stands of the greater equatorials consist of a solid pyramidical base

similar to that of the Dorpat refractor. One of this character, for example, is to be found in Munich, with a telescope of 8 feet focus and 6 inches aperture; the hour circle has a diameter of 9 inches, graduated to 4 seconds of time; and the declination circle, a diameter of 12 inches, divided to arcs of 10 seconds. The telescope, admitting a magnifying power of 400, follows, by means of a clock with a centrifugal pendulum, the diurnal motion of the stars.

The Theodolite.

90. Another instrument to be noticed in this place is the Theodolite. *Fig.* 35 represents a lateral, *fig.* 36 an edge, and *fig.* 37 a superior view of a Theodolite constructed by Ertel of Munich. In the three views the same letters refer to the same parts. It rests upon a tripod stand, AA, with three adjusting screws, of which only two, B, B, are represented. On this tripod is a short column, C, and upon this column is placed the horizontal circle E, graduated to degrees, &c. Upon this, and turning on its centre, the standards, H, H, rotate. These carry at their extremities, pivot holes for the horizontal axis of the telescope, N, whose optical axis moves in a vertical plane. The whole arrangement is similar to that of a transit instrument, with this difference, that the Theodolite has a very finely graduated vertical circle for measuring altitudes, while the horizontal circle, E, is intended to measure horizontal angles, which are read off by the lenses, G. This horizontal circle, E, can be fastened or loosened at pleasure by the clamp arrangement, F*abb*. K, K, are lenses or microscopes for reading off the vertical angles measured on the circle L, and M is the level required for rectifying the station of the instrument.

Theodolites are divided into two principal kinds—*Compensating* and *Repeating Theodolites;* they are also provided sometimes with a so-called rectifying telescope. As regards the use of the instrument, we would refer to what has been said of it in the mathematical portion of the work.

The errors and rectifications of the Theodolite are much the same as those of the meridian and transit instruments (sections 84 and 87). In conclusion, it may be remarked, that for the Theodolite may be substituted a repeating circle, a simple circle, or an universal instrument, as constructed by Ertel of Munich, and A. and G. Repsold in Hamburg. These instruments fulfil the aim of the Theodolite just as well, and even more completely; at least this is the case as far as regards astronomical observations.

The Reflecting Sextant; the Reflecting Sector; the Triquetrum.

91. All the instruments already mentioned, as used for measuring angles, require an immovably vertical or horizontal position. This, however, cannot always be attained, in which case reflecting instruments are

employed, which, by their constructions, compensate for the want of a fixed station. Among these belong first the *reflecting sextant.* This consists of a circular sector, amounting to from 60–65 degrees, and is an instrument of great value on land, but absolutely indispensable at sea. As, however, from the theory of the instrument, the angle indicated on the sextant is exactly half the true angular distance, every degree of the sector indicates two degrees of angular distance. The instrument, therefore, measures angles of 120° to 130°, on which account every half degree of graduation is marked as a whole degree. About the centre of the sector rotates an alidade, which carries a large plane mirror, passing through the centre of the sector; another somewhat smaller plane mirror is fixed perpendicularly to the plane of the sextant, and so adjusted, that when the alidade is brought to the zero point of the graduation, the planes of the two mirrors are parallel. This plane mirror is uncovered in its upper half, and in practice, the signal of one leg of the angle to be measured is seen by direct light, that of the other immediately under it by reflection. At the back part of the sextant, a handle of wood is attached, by which it is held during observation. Between the two mirrors are hinged variously colored glasses for the protection of the eyes when observing in a bright light. The astronomical telescope is screwed in such a manner into the frame that the objective end lies next to the mirror. The alidade carries a vernier with a lens for reading off the degrees. The sextant must not be too heavy, as it is to be held in the hand when in use. Sextants of greater dimensions, as of 8 inches radius and more, have stands specially adapted to them.

The errors of such an instrument must be ascertained before using it. The first of these is the error of collimation; the second, a want of parallelism of the axis of the telescope with the plane of the instrument; the third consists in an unequal distinctness of the direct and reflected image of the same object. The fourth error is when the sides of the mirrors are not accurately plane and parallel to each other; and the fifth has reference to the same circumstance in the colored glasses. All these errors must therefore be rectified before the instrument can be used.

The first application of the sextant is in measuring the angle between two objects at any direction with respect to the horizon. Here the least illuminated object is selected as the one to be seen by direct light. The second application is to the measurement of altitudes. To determine the altitude of an object by means of the sextant, look directly through the telescope at the image of the object in the horizon, which may either be a natural or an artificial one; bring the plane of the sextant into the vertical position, and move the alidade until the reflected image of the object covers its direct image: the angular position of the alidade will indicate double the altitude desired.

Pl. 15, *fig.* 23, gives a perspective view of another form of sextant with a glass prism, of simpler form and less expensive construction. ABB is the body, BB the graduated limb, C the movable alidade with the vernier, D the lens for reading off the graduation, GF the telescope, E the box containing

the prism, in which the two images must be brought in contact; the index will then give the angular distance of the two objects at the station of the observer. In this instrument the colored glasses are wanting.

92. Another kind of reflecting instrument formerly used in measuring angles of moderate value, is the *Reflecting Sector* (*fig.* 24), whose limb, DD, only contains somewhere from 10–15 degrees. The alidade carries the vernier E, with the double tangent screw, FF, for fine adjustment; I and K are the mirrors, GH the telescope with the bent ocular, H, so that the observer at H looks downwards into the telescope. At the present time the instrument is no longer used, owing to the difficulty of rectifying it. Even the reflecting sextant is but rarely employed on land, theodolites having taken its place, being equally convenient to carry when of small size, and giving angles with much greater precision. At sea, however, the sextant retains full sway, as there no other observing instrument can supplant it.

93. This is the appropriate place to refer to the *triquetrum* (*fig.* 21), an ancient instrument, supposed to have been invented by Ptolemy, for determining altitudes and amplitudes of the heavenly bodies. It consisted of a staff, A, placed vertically by the assistance of a plummet, D. Attached to this staff were two others, B and C, movable on hinges, and thus capable of forming various triangles with the first. On one of them, namely on B, were placed the sight vanes, *a* and *b*. The construction and use of the triquetrum (so called from its triangular shape) depended upon correct geometrical principles, although, as is very evident, observations made with it could be of but very superficial character

The Sun-Dial; the Gnomon.

94. Sun-dials are instruments by means of which the true solar time can be determined, when the sun is above the horizon and not obscured by clouds. Before the invention of wheel clocks, they formed the only means for an accurate determination of time. *Gnomonics*, a special department of applied mathematics, teaches the mode of constructing sun-dials on any plane or curved surface. Even the Egyptians were acquainted with the sun-dial; at least, Josephus expressly asserts that the obelisks served for astronomical observations; and Augustus caused an Egyptian obelisk to be erected in Rome for the same purpose. The Jews had them 732 B.C.; and as to their existence among the Greeks, they are to be found in the choragic monument of Andronicus Cyrrhestes in Athens. Papirius Cursor constructed the first sun-dial at Rome 290 B.C. Portable sun-dials were invented by Pope Sylvester in the tenth century.

Sun-dials consist generally of a face of proper form—the *dial surface*—upon which is an *hour ring;* on this latter, the shadow of a *style* or gnomon indicates the hours.

There are various constructions of dials, depending upon the position and character of the dial face. The simplest form, and the one most usually employed, is the *equinoctial* or *equatorial* dial, whose plane is parallel to the

plane of the equator. In this form the hour ring forms a circle divided into 24 hours. The shadow of a style erected perpendicularly to the centre of the dial face, indicates the hours whenever the twelve o'clock line of the dial is fixed in the meridian of the place, and the style rendered parallel to the axis of the earth. This equatorial dial can of course be employed to determine the 24 hours in those countries only where the sphere is parallel, or which have the pole in their zenith. In our latitude only the half circle can be used, and that only from vernal to autumnal equinox.

When the plane of the dial is parallel to the plane of the horizon, it becomes a *horizontal* dial. The meridian line of this dial must be in the meridian of the place, and the index in the direction of the pole. To construct a horizontal dial, draw the line of six o'clock, and, perpendicular to this and bisecting it, the meridian, or twelve o'clock line. At the point of intersection draw a line, forming, with the six o'clock line, an angle equal to the altitude of the pole, or the latitude of the place. Taking a moderate length on this line as hypothenuse, complete the right-angled triangle, by letting fall from its extremity a perpendicular on the six o'clock line. From the intersections of the first mentioned lines as centres, and with the hypothenuse, and that part of the six o'clock line belonging to this right-angled triangle, as radii, describe two semicircles on the six o'clock line. Divide each into twelve equal parts, and from each point of division of the inner semicircle, draw lines parallel to the meridian; and from each point of the outer semicircle, lines parallel to the six o'clock line. Through the intersection of these two sets of parallels, prolong radii of the semicircles. These latter radii, twelve in number, will be the lines of shadow cast by the edge of the style for the 12 hours intervening between 6 A.M. and 6 P.M.: when produced on the other side of the centre, they will indicate the hours from 6 P.M. to 6 A.M. Thus, 7 A.M. produced, will indicate 7 P.M., &c. The outline of the dial plane may be square or circular. The style of the dial must form, with its plane, an angle equal to the altitude of the pole at the place of erection. If the style have an appreciable thickness of material, it will be necessary in the construction to suppose the semicircle divided into quadrants, and these separated by a parallel-sided space, equal in breadth to the thickness of the style. Since a simple index post is easily bent and moved from the required angle, it is preferable to employ a right-angled triangle, whose hypothenuse forms with the base an angle equal to the altitude of the pole.

95. When the surface of the dial is in a vertical plane, it becomes a *vertical dial*, of which there are four forms, named after and corresponding to the four principal regions of the heavens: *morning* (oriental), *noon* (azimuthal), *evening* (occidental), and *midnight dials*, as the vertical planes are turned towards the east, south, west, or north. These dials may be constructed mechanically by means of an equatorial dial and the rays of the sun.

The surface of the dial need not necessarily be turned to any particular part of the heavens, nor be exactly horizontal or perpendicular, although the construction of these *declining dials* becomes more difficult, and requires a greater knowledge of mathematics. *Polar dials* are those traced on a plane

perpendicular to the meridian, and passing through the poles; the index is here parallel to the equator. There are also *cylindrical* dials where the surface is a cylinder; and *annular*, where the hour circle is marked on the inside of a ring. The rays of the sun falling through a hole in a hoop upon this circle, determine the hours. The portable dials are principally horizontal, and must be set up by means of a compass.

It remains to remark, in conclusion, that as the sun-dials indicate only the true, and watches the mean time alone, the two can only agree exactly twice in the year.

96. The *Gnomon* was a contrivance of the ancients, to determine the altitude of a luminous body above the horizon, by the shadow cast by a vertical style upon a horizontal plane. Anaximander made use of the gnomon to determine approximately the obliquity of the ecliptic at 24°; and after that, Pythias and Hipparchus calculated the solstices and altitudes of the sun. In all probability the obelisks of the Egyptians were nothing else than such gnomons, by means of which they obtained the culmination of the sun, and consequently the true noon, for the purpose of regulating their water clocks. An improvement of this apparatus is presented by the *Thread Gnomon*, in which the solar rays are received on a vertical wall perpendicular to the plane of the meridian, and the precise position of the meridian plane, passing through the centre of a circular aperture in the wall, indicated by a depending thread. It will be readily understood that the meridian lines required for each gnomon must be previously determined with the greatest possible degree of accuracy.

The Wheel Clock.

97. By the word *clock*, without further qualification, is meant every machine which, by means of the perfectly uniform motion of wheelwork, is intended to divide mean, solar, or sidereal time, into a certain number of equal parts; the minuteness and accuracy of these latter depending on the more or less complete elaboration of the component parts of the apparatus.

It is an ascertained fact that the first clocks were moved by weights. Galileo and Huyghens first applied the pendulum to regulate the motion of the clock by its regular oscillations. In the sixteenth century a spiral spring was used as a motive power instead of the weights, and the pendulum was replaced by the *balance wheel*. By means of these two substitutions, it became possible to reduce the mechanism of the clock within so small a compass, as to render it sufficiently portable for pocket use; and although the honor may be contested against him, Peter Hele of Nürnberg is to be considered as the inventor of watches.

98. This is not the place to go into a minute description of the mechanism of a clock; it must be remarked, however, that the motive power, whether bent spring or weight, acts upon a wheel with a certain number of teeth, and that by a proper arrangement of wheels and pinions, the indices are moved in such a manner that the one (the minute hand) makes twelve

rotations while the other (the hour hand) makes but one. There is often a third index (the second hand) which makes one rotation in a minute. In the better clocks the second hand springs from one second to another, thus showing each one separately; and as in astronomical clocks minute divisions of time are desirable, in these the division of seconds has sometimes been brought to thirds.

As the motive power can never act uniformly, every clock requires a regulator, which may compensate for the irregularities of the power. The whole wheelwork is consequently in such connexion with a single wheel—the escapement, that when the latter is checked the motion of the whole stops. This escapement, in the pendulum clock, is connected with the pendulum, which vibrates either whole or half seconds; the motion ceases, therefore, between every swing of the pendulum. It is thus seen that the proper motion of the clock depends upon the accurate length of the pendulum, and that as pendulums swing in proportion to their lengths, a clock may be regulated by lengthening or shortening the pendulum. The pendulum itself, however, needs regulating; for, being lengthened by heat and shortened by cold, the correctness of the clock's motion is impaired. As it is not possible always to determine this variation of length, and the variation is often very sudden, it cannot be provided for by any manual regulation. To meet this difficulty Harrison invented a compensation pendulum which regulates itself. In this pendulum, rods of brass and steel alternate in such a manner, that the elongation of the steel rods, and consequently of the pendulum, is counteracted by that of the brass rods, which in this manner shorten the pendulum as much as it is lengthened by the steel rods. Its length thus remains unchanged in all temperatures. Graham's mercurial pendulum is intended to accomplish the same end. (For further details see the article, Compensation Pendulum, under the head of Physics.)

In the second kind of regulators, all the wheels are connected with the balance wheel by means of the escapement, so that this produces the necessary check to the motion. Of escapements there are various forms, all, however, being in connexion with a balance, which is a flat wheel, on whose pallets the scape wheel catches, endeavoring to move it forwards. The pallets are so fixed on the verge of the balance wheel, that the scape wheel must leave them free after a certain time, and then the spiral spring acts upon the balance, bringing it back to the former position to meet a new tooth of the escapement. It will be readily seen that the quicker or slower motion of a clock will depend upon the time in which the balance makes its movement, and that this time depends upon the length or shortness of the spiral spring. There is for this reason a regulator on the watch whose motion alters the length of the spring.

As in the pendulum isochronism of oscillation is effected by the principle of compensation, so in the balance there must also be a compensation, since both it and the spiral spring change their dimensions, and consequently their times of vibration, with change of temperature. Compensation is brought about in the balance by the bending of thermometric metal springs, steel

and brass, or platina plates, being so combined that their changes through temperature counterbalance those which, for the same reason, take place in the balance.

99. Clocks for astronomical purposes must be very carefully constructed, and every tendency to inaccuracy must be specially counteracted. They may be pendulum clocks, as used in observatories, or balance clocks—*chronometers*—as employed at sea to assist in the astronomical determinations there necessary. The English, to whom the perfection of chronometers is due, set great value upon the best of them, and Harrison furnished instruments which, in a voyage round the world, did not vary three seconds. Such chronometers are little different in construction from the best watches, except in having a peculiar escapement; all their parts are, however, very carefully constructed, many precautions taken against accidental injury, and throughout, compensations for the effects of temperature and other physical agents (as magnetism) introduced. Longitude or marine time keepers (box chronometers) for nautical and astronomical purposes, are constructed just like the pocket chronometers; they are, however, larger, and inclosed in a special box.

The Planetarium.

100. Among the numerous helps to the study of astronomy and mathematical geography, must be mentioned those artificial models and contrivances known under the names of *Lunarium, Tellurium,* and *Planetarium.* The lunarium is an apparatus by which the motions of the moon about the earth, her phases, &c., can be readily illustrated and explained. It is usually combined with the tellurium. The tellurium, called sometimes *geocyclic machine,* is a particular form of planetarium, which exhibits the motion of the earth round the sun, the course of the moon about the earth, and with her about the sun, as also all attendant phenomena, such as the seasons, quarters of the moon, &c. Finally, the planetarium is a model, intended to render perceptible to the senses the motions of the planets and all resulting phenomena, on which account it has received various constructions. Common planetaria are moved by hand; the better and more complicated have a wheelwork, which, like a watch, is set in motion by a spiral spring, and causes the planets to revolve with their respective velocities around a globe or lamp placed in the centre. As Lord Orrery was the first to construct a planetarium of this character, they are sometimes known as *Orreries.*

Henderson, formerly director of the Edinburgh observatory, has published the description of a simplified planetarium (*pl.* 15, *fig.* 38), whose construction will be here briefly mentioned. In a circular box standing on four feet, the clockwork is set in motion by the handle D. Upon the upper surface of the box are marked the ecliptic, the perpetual calendar, and other items relating to the planets. In the centre is a large sphere representing the sun, about which the planets revolve on vertical posts fastened to horizontal

rods, with their proportional velocities, and at their proportional distances—Mercury, H; Venus, G; Earth, F, with the moon, *c;* Mars, I; Jupiter, M, with four moons, *e, e, e, e;* Saturn, N, with the ring, and the seven satellites, *f, f, f, f, f, f, f;* as also Uranus, K, with the six moons, *d, d, d, d, d, d. Fig.* 39 represents a contrivance, which, attached to this planetarium, serves to give the earth's axis a parallel motion, and to exhibit the cause of the seasons and their succession. It consists of the small globe, F, to whose equator the hollow brass tube, E, is fastened, which carries the weight, C, and the carrier, D. If now the planetarium be hung to the wall by the ring E (*fig.* 38), and set in motion, C being held fast, the earth will revolve, her axis remaining constantly parallel, and thus representing the courses of the seasons, which are indicated on the fixed disk, A.

The best Planetaria and Telluria are those of Riedig and Schulze in Leipzig, and Seifert of Hohenstein near Chemnitz in Saxony.

101. It remains to mention, in conclusion, that there are still other pieces of apparatus, some of them ancient, and others more modern, which are used with excellent results both by the practical astronomer and the teacher. Among these may be mentioned the *circle micrometer*, as also the *differential micrometer* (invented by Boguslawski) for determining the difference of right ascension and declination of two stars: the *dipleidoscope* (invented by Dent of London), an apparatus which replaces the transit instrument; the beautiful model by Möbius of Leipzig, for representing the orbits of the asteroids, Ceres, Pallas, Juno, and Vesta, with respect to their magnitudes, inclinations, and eccentricities; finally, the *mercurial* clock of Kater, and the *astrograph* of Steinheil.

Observatories.

102. The place where astronomical observations are conducted and the necessary apparatus erected, is called an *observatory*. The choice of such a place is sometimes very much restricted; where this is not the case, it should be established in a dry locality, where, remote from all motion which might produce vibrations, the foundations and lower stones of the buildings and the instruments may be protected from the influences of weather and temperature. The building itself must be constructed in the most solid manner, and, if possible, facing the four quarters of the heavens. It is desirable to have an elevated station from which the horizon can be surveyed in every direction; where this is impossible, the parts of the building in which are placed the principal instruments must be much elevated. The foundations of the edifice must be very solid, and each principal instrument must have an isolated base, or must be connected with the ground by special foundations, not touching any part of the edifice, in order that all shaking of the instrument may be avoided. A free view in all directions must be had, and for the meridian there must be a vertical slit passing through the whole height of the building. The place also where the refractor, or other instrument supplying its place, stands, must be so arranged that the whole of a vertical plane can be seen

in any direction, for which reason there is generally a roof attached which turns on a railroad, or can be entirely removed. In the first case, the roof is divided by a vertical section of four feet in breadth, into two halves; the aperture, however, can be closed by trap-doors. Such an arrangement, for example, is to be found in the building for the great refractor at Dorpat, and in the turning cupola of the observatory at Washington.

The best observatories are those at Altona, Berlin, Dorpat, Göttingen, Greenwich, Königsburg, Mailand, Munich, Ofen, Pulkowa near St. Petersburg, Seeberg near Gotha, Vienna, &c. In the other parts of the world, those at the Cape of Good Hope, Paramatta in New South Wales, and in the United States, are the best known. In the United States, the principal observatories and instruments are at Cambridge, Philadelphia, Washington, Cincinnati, Hudson (O.), &c.

Practical Astrognosy.

103. The finding of particular stars and constellations is effected by means of the celestial globe and star maps; as also by the method of *alignments* already mentioned (sec. 26). This latter method will now be detailed a little more at length. It was there seen that from the position of the Great Wain, or the Great Bear, the polar star could be determined; and in the same manner other stars are identified. For this the star maps (*pl.* 12) are employed, on which the alignments of the principal fixed stars are given. Produce the direction of the stars ζ and η towards the wain, it will strike a star of the first magnitude, Arcturus in Bootes, which, with the polar star and Vega in Lyra, forms an isosceles triangle, Arcturus being at the vertex. The polar star, which, by its almost unchangeable position, is very well calculated for the purpose, serves as a point of departure for the rest of the heavens; the altitude of the polar star above the horizon being nearly equal to the geographical latitude of the place. Twice the length of a straight line from Vega to Arcturus strikes Spica, a star of the first magnitude in Virgo. Spica forms, with Denebola (in Leo) and Arcturus, and also with Arcturus and the star α Libræ, triangles nearly isosceles. Spica forms the vertex of the first of these; Arcturus of the second. The star α Libræ lies almost in the continuation of the connecting line between the polar star and Arcturus. Furthermore, the alignments of Vega, the polar star, Capella, and Aldebaran, form a large flat arc. Aldebaran, a star of reddish light, is one of five stars lying near to each other, which form a V, and are called Hyades. Aldebaran and Capella form an almost right-angled triangle with Castor, a star in Gemini. A line drawn from Denebola to the polar star, and produced some distance beyond, strikes a bright star, which, with three others, forms a large almost regular quadrilateral, the greater part of Pegasus. A line from Perseus to Aldebaran, and sufficiently prolonged, strikes three bright stars, the belt of Orion. Produce the line indicated by this belt to the left, and it will meet the brightest star in the sky, Sirius (the Dog star). In this manner, straight lines may in succession be drawn from two known stars to others, and the triangles thus formed, constructed in the heavens.

104. With the help of a celestial globe, the same end may be attained more readily, by setting up the sphere for the place of observation, as also for the day and hour of observation. It is then only necessary to look in what direction and at what elevation above the horizon any star is found on the globe, and then direct the eye towards the corresponding part of the heavens, to be able to identify them on both spheres. In this way, for instance, it might be observed by means of the celestial globe, that at $7\frac{1}{2}$ o'clock of Jan. 18, a star of the first magnitude, Capella, stands a little to the south-east of zenith, outside of the milky way. It is then only necessary at that time to look a little to the south-east, out of the milky way, actually to see Capella.

105. Knowing the twelve constellations of the zodiac, it will not be difficult to find the visible planets, Mercury, Venus, Mars, Jupiter, Saturn, and even Uranus, in these constellations, distinguishing them with certainty from the fixed stars by their peculiar appearance and their varying position with respect to the neighboring stars.

PHYSICS.

PLATES 16–22.

IN the general introduction to the preceding portion of the work a concise summary of the entire system of the natural sciences was given, in which *Physics*, in a restricted sense, or *Natural Philosophy*, occupied a very important place. The following sections will be devoted to this science. In the above-mentioned introduction the system was traced out in its broadest features. Taking the general divisions there indicated, it will be now necessary to subdivide them, and to examine each subdivision with special attention.

Natural Philosophy, or Physics, may be divided into *pure* and *applied*. *Pure Physics* will then form the theoretical portion of the science, teaching the laws of nature, as far as they may be inferred from careful and long continued observations of natural phenomena, afterwards verified and established by actual application to practice. Hypothesis can only be verified by its enabling us to develope the phenomena belonging to a certain class, and to predict the manner of their occurrence under certain circumstances, and at certain times. In this way Newton deduced the flattening of the poles of the earth from the law of gravitation; Laplace calculated the two different diameters of the earth, and actual measurement has proved the truth of his results. The predictions of astronomy are founded on such theories; and the actual occurrence of solar and lunar eclipses, and other similar phenomena, years after they had been foretold, shows the firm and sure ground on which these theories are based. This discovery of natural laws is then the object of *pure physics*, while the application of the laws thus found to surrounding nature, belongs to the department of *applied physics*. The various sections of the latter are referred to in their appropriate places in this work: attention will be directed for a moment to pure natural philosophy.

The single branches of science with which pure natural philosophy is occupied, are, 1, the theory of equilibrium of forces, or *statics;* 2, the theory of motion, or *dynamics*. These two parts taken together form what is generally termed *mechanics*, properly a part of applied mathematics. 3, the philosophy of sound, *acoustics;* 4, of light, *optics;* 5, of heat, *pyronomics;* and 6, of *electricity* and *magnetism*, which latter have in more recent times made astonishing progress.

A few general observations on the peculiarities of bodies must precede the minute investigation of particular parts of the subject. We refer to

those peculiarities which form the essence of what is known as *body*, *matter*, *material*, which thus apply to all bodies without any exception. Among these peculiarities may be first mentioned *extension* and *impenetrability*. A body must have a certain extension, that is, must occupy a certain space; it must nevertheless be impenetrable, or must fill this space in such a manner, that no second body can also occupy it at the same instant of time. We must not fall into the error of supposing that one body can penetrate another, as a nail can a board, in the physical sense of the word. As the nail is driven through the board by mechanical force, it pushes aside the fibres of the wood, and occupies their place; the particles of the wood and iron are therefore contiguous, but not in the same place. *Penetration*, in the physical sense of the word, is the destruction of one substance by another, not a mere displacement. In the latter case, there is not necessarily an increase in bulk, as the board with the nail occupies no more space than without it; and a measure of water mixed with a measure of sulphuric acid will not fill two measures: penetration, nevertheless, has not taken place, no atom having been annihilated, as may be proved by weighing. *Divisibility* is another general property of bodies, by means of which they are supposed to be capable of division into smaller and smaller portions—atoms. The pulverization of solid bodies, the small globules of fluids, as the blood globules, whose diameter is only $\frac{1}{450}$ of a line, and the great space which gaseous bodies can occupy, show this property on a large scale, while the atomic theory follows it to the smallest molecules. Nearly allied to divisibility, are two other properties of bodies, *extensibility* and *compressibility*, which are opposed to each other. By these terms is meant an increase or diminution of the space which a body, under certain circumstances, occupies, without the connexion of its molecules or atoms being thereby affected. As these atoms are supposed to be unchangeable, this change of space must necessarily be referred to an expansion or contraction of the interspaces which exist between these atoms, in the natural state of the body. This extension is the result of a stretching or heating; the contraction takes place under the influence of cold or pressure.

The mention of interspaces between the individual atoms of a body, leads us to the consideration of another property of bodies, called *porosity*, possessed, as far as we know, by all. In ordinary language, however, the term *pore*, which may be considered, scientifically, as referring to an interspace infinitely small, is applied to those only which are large enough to allow the passage of fluids or gases. It is by means of these pores that the parts of one body penetrate between those of another, as water a sponge. In other bodies the pores are so small as not even to admit the entrance of gases, as, for instance, glass.

The atoms of which a body is composed are not always homogeneous, and hence the different kind of bodies; thus cinnabar is composed of atoms of sulphur and mercury; water, of oxygen and hydrogen atoms, &c.; such bodies being called *compound*, as distinguished from *simple* (elementary or elements), in which the atoms are homogeneous. These investigations, however, belong to the department of chemistry, and as such, do not belong

to this subject. The manner in which atoms are combined, or their *aggregation*, is also deserving of mention, as the same atoms may be considered as combined under different forms and conditions; thus, ice, water, and steam, are all composed of oxygen and hydrogen, in the same proportions, yet all possess very different properties. Three conditions of aggregation are known, according to which bodies are divided into *solid*, *liquid*, and *gaseous*.

By *solid* bodies are to be understood those which, apart from the changes produced by heat and mechanical agency, have an unchangeable volume, and an independent definite form. In these the single atoms are brought in the closest possible connexion. The connexion of atoms in *liquid* bodies is less intimate, possessing an almost unchangeable volume, even when a small quantity is exposed to great pressure; they have, however, no definite form. In *aeriform* or *gaseous* bodies, the connexion of the atoms is exceedingly slight, there being neither an unchangeable volume nor a determinate form, both depending upon surrounding influences. All bodies, under certain circumstances, may be transformed from one condition of aggregation to another, although the means to be employed, namely, change of temperature and pressure, may not be applicable to a sufficient degree to effect this in certain cases. Thus, for example, mercury at a temperature of, and below —39° F., is a solid; at the ordinary temperature, it is a liquid; and by an increase of heat, it becomes converted into vapor. Inversely, watery vapor, by cooling, becomes a liquid: water—and a still further reduction of temperature turns this into a solid: ice. Mercury also can be converted from a vapor into a solid in the same way. Faraday, within a recent period, has succeeded in converting many gases into liquids and solids, for which great cold and pressure were both necessary.

There must be a certain force which maintains the single atoms of a body in their mutual situations, giving to these bodies their structure and external form; another force again must cause the tendency to separation exhibited by these atoms, as among the gases. These two molecular forces are the force of *cohesion* or *attraction*, and the force of *expansion* or *repulsion;* and as heat converts solids into liquids, and liquids into gases, it has been customary to consider heat and expansiveness as identical. The predominance of one or the other force determines the conditions of aggregation in a body. In solids, the former predominates; in gases, the latter; in liquids, the two are in equilibrium.

Bodies may be considered under two conditions, namely, in a state of rest, and of motion; and this consideration brings us to another general property—that of *inertia*. Neither a part nor the whole of a body has in itself any tendency to change its present condition, that is, to pass from a state of rest to one of motion, or the contrary. The first case is illustrated daily; the second, however, although true, is not so evident, as we see everything come to rest, after a time, from a state of motion. The cause of this cessation of motion, however, is not in the body itself, but in external influences operating upon it: if these latter be neutralized, the motion continues. The principal obstacles to a continuation of motion are—friction,

and the resistance of the atmosphere. The motions of a body will continue in proportion as these influences are counteracted. Thus, a top will spin on the smooth plate of an air pump, under an exhausted receiver, for hours after being set in motion. A body opposes a certain resistance to the force attempting to overcome its inertia, so that every motion is conditioned, on the one hand by the intensity of the influencing force, and on the other by the force of resistance of the body: its *mass*. The mass of a body is the amount of matter of which it is composed.

A body let fall from a height will descend till it meets some obstacle. This is produced by *gravitation*, another general property of bodies. The *falling* of a body is, however, not the only result of gravitation. But more of this hereafter. The direction of gravitation coincides completely with the direction of a body suspended freely from a thread, as, for instance, a plumb-line; this direction, therefore, is called perpendicular, plumb, or vertical: the surface of standing water, as will be learned hereafter, is perpendicular to this elevation. From this mutual relation has been deduced the proposition, that the direction of gravity is always perpendicular to the earth's surface. As, however, the earth's surface, or the water surface, is that of a spheroid, the perpendiculars to it must be in the direction of the radii produced; whence it follows, that the direction of gravitation always tends towards the centre of the earth. Hence vertical lines are not parallel to each other, a fact which becomes inappreciable at short distances. At a distance of 600 feet, for example, the angle at the centre of the earth, between two perpendiculars, amounts only to about $6\frac{1}{3}$ seconds.

The force of gravity is exhibited by *pressure* when opposed to a resistance. The magnitude of this pressure is termed *weight*, this increasing with the number of material particles of which the body is composed, so that as the mass of a body is always proportional to its weight, the latter serves as an expression of the former.

There remains to mention, in conclusion, among the general properties of bodies, their *density;* in other words, the proportion of their weight to their volume. All bodies have a certain density, which depends upon the mode of aggregation, and the material of their single atoms. This density is termed *specific gravity*. As it is necessary to have a standard to which all densities may be referred, the weight of pure water, in its greatest density, has been taken as the unit of reference. By the density, then, or specific gravity of a body, is to be understood the ratio which its weight bears to an equal volume of pure water. If a certain mass of iron weigh 7.8 lbs., while an equal volume of water weighs 1 lb., the specific gravity of the iron is said to be 7.8. More will be said hereafter as to the proper mode of determining specific gravities.

MECHANICS.

A. The Statics of Solid Bodies.

a. General Ideas.

When two or more forces, acting in different directions upon the same body, are so adjusted as completely to neutralize each other, no change being produced in the body, the body is said to be in *equilibrium*, or the forces are said to hold each other in equilibrium. Statics investigates the conditions of equilibrium in bodies, being divisible into three sections, according to the three different states of aggregations: statics of solids—*Geostatics;* statics of liquids—*Hydrostatics;* and statics of gases—*Aerostatics.* The laws of the motions produced, when, among the different forces, the laws of equilibrium are not satisfied, are investigated by *Dynamics.* This, also, is divisible into dynamics of solids—*Geodynamics;* dynamics of liquids—*Hydrodynamics*, or *Hydraulics;* and dynamics of gases—*Aerodynamics*, or *Pneumatics.*

A point acted upon by a single force must move in the direction of the force and likewise, in a straight line. Equal forces are those which, when acting in diametrically opposite directions, neutralize each other completely. Two equal forces acting in the same direction are equal to twice the amount of one of them acting in this direction: several forces, even though unequal, act, in the same direction, as a single one equal to their sum. This is called the *resultant.* Resultants acting in precisely opposite directions, neutralize each other either entirely, when equal, or partially, when unequal: in the first case there is equilibrium, in the second there is motion, in the direction of the greater resultant. If the forces act at an angle with each other, motion is in a direction between them, obeying a mean force, the resultant of the different lateral forces. The magnitude and direction of this mean force is known from a law called the *parallelogram* of forces, explained by *pl.* 16, *fig.* 1. Let the lines AB, AC represent the direction and intensity of two forces, acting at the same instant on the body A. Completing a parallelogram from the angle BAC, and its sides, AB and AC; DA, the diagonal of the parallelogram, ABDC, will represent the direction and intensity of the force, which, if acting alone upon the point A, would produce the same effect upon it as the two simultaneous forces BA and CA. If a lateral force be supposed capable of urging the point A as far as B in a certain time, and another lateral force be capable of carrying it to C in the same time, the two together will carry it from A to D.

In a manner similar to the preceding, by which two forces may be considered as one, one force may be separated into two, of which it may be considered the resultant. The problem then becomes, to determine the intensity and direction of two forces, which, acting upon a body at a given angle, shall produce the same effect as the single given force. Suppose, for instance, that in *pl.* 16, *fig.* 2, the force AC act upon the body A, and it be

desired to divide this into two others, of which one, AD, shall be given in intensity and direction; then the other force will be found in intensity and direction by the third side, CD, of the triangle ACD. Draw, for instance, AB parallel and equal to CD, then AB and AD will form two sides of the parallelogram of forces, whose diagonal is the given mean force, AC, this being the resultant of the two forces AB and AD, determined in intensity and direction. If neither of the lateral forces be given in intensity and direction, then the first might be assumed at pleasure.

When three forces, AB, AC, AD (*fig.* 4), act upon a body, the resultant of the first two may be found, then that of this resultant and the remaining force. The diagonal, AG, proceeding from A, will be that of a parallelopipedon, which may be constructed from the edges, AB, AC, AD. This parallelopipedon is called the *parallelopipedon of forces*, by means of which it becomes possible to determine the direction and intensity of the mean force, when the three forces, AB, AC, AD, do not lie in the same plane. In this case, supposing AB, AC, AD, to be projections of these forces, then the line AG will be the projection of the diagonal of the parallelopipedon formed on these three lines—in other words, the projection of the resultant of the three forces; and in the theory of projection we have already learned how from the projection of a line to obtain its true size and direction.

The mean force of three or more forces acting together on a body, is found by the simple construction in *fig.* 3. From the extremity, B, of the line AB, representing one of these forces (any one being taken indifferently), draw a line, BC‴, parallel and equal to the second force, AC; from C‴, a line, C‴D‴, parallel and equal to the third force, AD; from D‴ the line D‴E‴, parallel and equal to the fourth force, AE. The line AE‴, drawn to the extremity of the last of these parallels, will be the mean force required. That the line A*c* is, in magnitude and direction, the general resultant, is a consequence of the fact that, when the parallelograms of forces, ABB′B″, ACC′C″, ADD′D″, AEE′E″, are constructed on this mean force, the single forces, AB″+AC″+AD″+AE″=AE‴, and that all the parallelograms have a common side in the line B′E′.

An equilibrium between three forces must occur whenever any two of the forces are equal and opposite to the third. The proposition of the parallelogram of forces can be exhibited practically. Let, in *fig.* 15, the points A and B be fixed pulleys, in the same vertical plane, over which is passed a string. Let now the weight, W, act on one end of the string, W″ on the other, and W′ between the two, then all will be in equilibrium in any one position of the string. Three forces are now acting upon the three points, A,B,C, in the directions CA, CB, and CW′. It can be readily shown whether the law of the parallelogram has its application here. Suppose, now, that W = 2 lbs., W″ = 3 lbs., the question becomes, what must be the magnitude of W′ when the angle ACB is, for example, = 120°. Construct a parallelogram of which one side = 2, the other = 3, and the angle included between the two = 120°, and find the diagonal about = $2\frac{3}{4}$, making the weight of W′ = $2\frac{3}{4}$ lbs.; then the angle ACB, made by the string, will be = 120°. DB represents the amount of the force W″, AE that of W, and

CE that of W′. *Pl.* 16, *fig.* 16, extends this construction to the case of several weights, and forms the basis of the Funicular Machine of Varignon, of which more hereafter.

It is known that every body is subject to the influence of gravitation, and that this gravitation acts upon every molecule of the body. All these single influences of gravitation may be considered as united into a mean force of gravitation, which then is called the *weight* of the body. This union can and must take place in a single point, the *centre of gravity;* and a force acting on this centre of gravity, and equal to the weight of the body, will hold it in equilibrium. Gravity and weight, therefore, differ as cause and effect. Gravity is that natural force which causes the weight of bodies, and the centre of gravity the point in which the entire weight of the body may be supposed to reside. It is a fixed point, whose situation does not change, whatever be the position of the body. Whenever this point is supported in any way, the body rests in equilibrium.

The centre of gravity of homogeneous bodies of regular shape, is easily obtained by geometrical constructions. The centre of gravity of a straight line is evidently at its middle point (*fig.* 5). That of a triangle, ABC (*fig.* 6), lies where lines drawn from the angles to the centres of the opposite sides intersect each other. It may also be found by drawing a line from one angle to the middle of its opposite side, and trisecting this line; the first point of division, S, starting from D, will then be the centre of gravity. That DS must equal $\frac{1}{3}$DB, is shown by drawing DE; DE will evidently $= \frac{1}{2}$AB. The triangles DSE and ASB are, however, similar, whence SD : SB : : DE : AB; as, however, DE $= \frac{1}{2}$AB, SD must $= \frac{1}{2}$SB $= \frac{1}{3}$DB.

The centre of gravity, S, of a parallelogram, ABCD (*fig.* 8), is the intersection of its diagonals; that of a regular polygon, ABCDEF (*fig.* 7), as also of a circle, is the centre. If a rectilineal figure of an even number of sides, as, for instance, the six-sided one, ABCDEF (*fig.* 7), be so constituted as to be divisible by a diagonal, CF, into two symmetrical halves, the centre of gravity will lie in the middle of this diagonal. If, moreover, as in the figure, all diagonals have a common point of intersection, this point itself will be the centre of gravity.

In those bodies which have a regular shape, and whose mass is distributed with perfect uniformity, the centre of gravity may be likewise determined geometrically. Thus, the centre of gravity of a cube or parallelopipedon is also in its geometrical centre: it is obtained either by passing a plane through two opposite edges, AB, DE (*pl.* 16, *fig.* 10), and finding the centre of this plane, or by finding the centres of gravity, S, S′ (*fig.* 11), of two opposite planes, and bisecting the connecting line at S″. From the first method it follows that the centre of gravity of a parallelopipedon lies in the point of intersection of two of its diagonals.

The centre of gravity of a pyramid (*fig.* 12) is obtained by connecting the apex, G, with the centre of gravity of the base, S, and on this line cutting off the fourth part from the base, so that SS′ $= \frac{1}{4}$GS. The centre of gravity of the cone is found in a similar manner. To obtain the common centre of gravity of two different bodies, as of the cubes AG and *ag* (*fig.*

13), obtain first the centres of gravity, S and *s*, of the two, by means of diagonals, and unite the two points by the straight line, S*s* ; upon this latter determine the centre of gravity, S′, as will be explained more fully under the head of the lever. The same method is to be pursued in determining the centre of gravity of irregular surfaces, as for instance, ABCD (*fig.* 9).

b. Of Simple Machines.

Simple machines, or *mechanical powers*, are those simple arrangements of which all machinery is compounded. Of these, six are generally distinguished: the *lever*, the *wheel and axle*, the *pulley*, the *inclined plane*, the *wedge*, and the *screw*. All these, however, may strictly be reduced to two—the lever and the inclined plane; on which account these two are looked upon as the elementary machines. The ancient Greek mathematician, Pappus, enumerates the above-mentioned simple machines, with the exception of the inclined plane, which is of more recent introduction. Instead of the latter power, Varignon added the funicular machine to the five others, which, however, consisting simply of ropes on which the forces act in different directions, and being intended to elucidate the proposition of the composition of forces, cannot properly be called a simple machine. See *fig.* 14, where the forces act in the same plane and in different directions upon the combined ropes at A, E, P, P′, P‴. These will hold each other in equilibrium when BC is equal and opposite to the mean force of BA and BP′, CD equal and opposite to the mean force of DE and DP‴, and CP equal and opposite to the mean force CB and CD.

The mathematical lever, in its simplest form, is an inflexible line supported in one point (*fulcrum*, *hypomochlium*) on which two or more forces operate, endeavoring to move it about this fulcrum. The distances from the fulcrum to the points of attachment of the forces are the *arms of the lever*. There are two kinds of levers: *levers of the first class*, or double-armed levers, in which the forces operate on different sides of the fulcrum; and *levers of the second class*, or one-armed levers, in which these act on the same side. The same conditions of equilibrium, however, apply to both, viz. that the forces must be inversely as the arms of the levers. Thus, when the arms of the lever are equal, the forces must be equal, and when the arms are unequal, the forces must be unequal, the greater force acting on the shorter arm, and the lesser force on the longer arm, these forces being in the same proportion as the arms of the lever. *Pl.* 16, *fig.* 23, represents a lever of the first class, in which the acting forces are the weights, P and W. F is the fulcrum, and for equilibrium, the proportions P : W : : BF : AF must exist. *Fig.* 25 represents a lever of the second class, which is supported at F, and operated upon in opposite directions by the weight W and the weight P, passing over the pulley and attached to A, the former weight drawing the lever downwards, the latter raising it up. Equilibrium can only subsist when P : W : : BF : AF. *Fig.* 26 is properly a lever of the second class, although in it the fulcrum is

above, and the force, P, draws upwards, while the weight, W, draws downwards. This form by some has, for this reason, been called a lever of the *third class*. In this lever, the above-named conditions still hold good, and the same is the case in the bent lever (*fig.* 30). Here, however, the bend of the arms, A′F and FB′, of the lever, is not to be considered, but only the direct distances from the fulcrum, B′*b* and A′*a*, or the levers, AF and FB, equal and parallel to them. Here also in a state of equilibrium we have P : W : : BF : AF.

Hitherto we have had reference to the mathematical lever, that is, to a line without weight; if the actual material lever be the one in question, where the weight of the arms of the lever comes into account, then the same proportions of the arms of the lever being retained, but with greater curvature of one or other arm, and consequently greater weight, the proportion, P and W, might change greatly without any disturbance of equilibrium.

Considering closely the proportion P : W : : BF : AF, we have P . AF = W. BF, this product of the two extremes and the two means being called the momentum of the forces. The *momentum* therefore of a force, is the product of the force by its leverage, and the preceding laws can be expressed in shorter phrase, by saying, a lever is in equilibrium when the momenta of the forces acting upon it are equal.

The case is somewhat different when the forces acting on the lever are not parallel to each other, as in *fig.* 29, where the two forces, P and W, are carried over pulleys. In this case each of the two forces must be decomposed into two others, of which one is perpendicular, and the other parallel to the lever. Expressing P by DA, and W by BG, calling also the angle, DAC, α, and the angle, GBE, β, then the force, DA, may be divided into the two forces, AC = P cos. α, and DC = P sin. α; the force, BG, likewise into BE = W cos. β, and EG = W sin. β. The proportion then becomes P cos. α : W cos. β : : BF : FA. This proportion only holds good, however, when the lever can only turn on the fulcrum without shifting. Should it lie but loosely upon the fulcrum, there must be equilibrium of the horizontal part of the forces, and the proportion P : W : : sin. β : sin. α.

Among the numerous applications of levers of the first class is to be reckoned the *balance*, that arrangement by which the weight of a body is determined. The common balance consists of an equal-armed lever, in which the two forces—the body, P, to be weighed, and the weight W—must act perpendicularly to the two arms of the lever. In the equality of the arms of the lever, the forces must necessarily be equal, that is, the weight to the weighed. When one beam of the balance is longer or heavier than the other, by even a very slight amount, the equality of the weight and the object weighed is destroyed, and the balance is false.

In the *steel yard* (*pl.* 16, *fig.* 24) other conditions of equilibrium exist. In this the beam, AB, is a lever of unequal arms; the arms, BF and AF, are supported at F, where the balance is either suspended as in the figure, or else held in the hand. A definite proportion exists between the lengths of the two arms, as 1 : 4 or 1 : 10, &c., and the forces will, according to the

preceding law, be inversely proportional to the lengths, that is, one pound at the end of the longer arm will balance 4 or 10 pounds at that of the shorter. As the short arm, BF = C, is fixed, and the weight, W, subject to great variation, and as the counterpoise, P, is likewise constant, the arm, AF = D, must be variable to hold any weight, W, in equilibrium. This is attained by shifting the point of suspension of the weight, P. Thus, let BF = 1, AF = 4, P = 2, then will P : W : : BF : AF, or 2 : W : : 1 : 4; then W = 8, and 2lbs. at A will balance 8 at B. If, however, W weigh less than 8lbs., then A hanging at P, the arm AF will preponderate, and P will have to be shifted towards the fulcrum. Supposing equilibrium to occur at D, and that DF = 3, then we shall have the proportion 2 : W : : 1 : 3, and W will be equal to 6. This mode of calculation is, however, too tedious in practice, and therefore the long arm, AF, is previously graduated in such a manner, that when the weight and the counterpoise are in equilibrium, a number on the scale opposite the latter indicates the amount of the former. It is evident that the balance is accurate only so long as BF, P, and FA, remain unchanged in length or weight.

The law of the lever finds numerous applications in the determination of the centre of gravity. To obtain the centre of gravity of an irregular figure, as of the quadrilateral, ABCD (*fig.* 9), divide it by a diagonal into two triangles, determine by the preceding methods their centres of gravity, and consider the connecting line, SS′, of these centres. as a lever upon which, at S and S′, forces operate proportional to the surfaces of the two triangles. The centre of gravity or fulcrum, S″, is obtained by dividing the line, SS′, in such a manner, that SS″ : S′S″ : : triangle BCD : triangle ABC. By continuing this process the same end may be attained for figures of more than four sides. The centre of gravity of two combined bodies, BE and *be* (*fig.* 13), is obtained by uniting their separate centres of gravity, and dividing the connecting line, S*s*, into two such parts at S′, that the distances of this point from the centres of gravity shall be inversely proportional to the masses of the two bodies.

If more than two forces act on one lever, striving to move it in two determinate and opposite directions, equilibrium occurs when the sum of the momenta of all the forces acting on one arm, is exactly equal to that of the forces operating upon the other arm. Thus in *fig.* 27 must $P . AF + P' . A'F + P'' . A''F = W . BF + W' . B'F + W'' . B''F$. When the forces on the same arm of the lever operate in different directions, some upwards and others downwards, as in *fig.* 28, then equilibrium takes place when the difference of the momenta of the forces acting on one arm, is equal to the same difference in the momenta of the forces operating upon the other arm; thus, when $W . AF - P . CF = P' . DF + P'' . EF - W' . BF$.

Fig. 31 represents a compound lever, consisting of three simple levers, AB, A′B′, A″B″, acted upon in opposite directions by the weights P, W. Upon the middle lever, whose fulcrum is F′, the force $\frac{P . AF}{BF}$ operates at A′, the force acting on $B' = \frac{W . B''F''}{A''F''}$: both of these forces press A′B′ upwards,

and to produce equilibrium, $\frac{P \cdot AF}{BF} \cdot A'F'$ must $= \frac{W \cdot B''F''}{A''F''} \cdot B'F'$, or $P \cdot AF \cdot A'F' \cdot A''F'' = W \cdot BF \cdot B'F' \cdot B''F''$.

The lever considered thus far has been the mathematical or weightless one; in practice, however, its weight must be taken into account as acting at its centre of gravity. Calling, therefore, the weight of the lever Q, and the distance of the centre of gravity from the fulcrum, q, the conditions of equilibrium in *fig.* 23 will be $P \cdot FA + Qq = W \cdot FB$; for *figs.* 25, 26, and 30, $P \cdot FA = W \cdot FB + Qq$; for *fig.* 29, $P \cdot \cos. \alpha \cdot FA = W \cos. \beta \cdot FB + Qq$; and for *fig.* 27, $P \cdot FA + P' \cdot FA' + P'' \cdot FA'' = W \cdot FB + W' \cdot FB' + W'' \cdot FB'' + Qq$.

The general principles of the rectilineal lever apply to the case of bent levers, or those whose arms form an angle with each other at the fulcrum. Here, however, equilibrium is established when a line drawn from the fulcrum, perpendicular to the straight line connecting the extremities of the lever, divides this line into two parts which are inversely proportional to the forces acting on the ends of the lever. The *bent lever* is much more sensitive than the straight, when its angle is directed upwards, for which reason, in the better scale-balances, the beams are not rectilineal levers, but the fulcrum or point of suspension is generally somewhat lower than the points of attachment of the weights.

To the preceding proportions respecting the lever, it becomes necessary to add, that in every lever, the spaces traversed by the arms of the lever are inversely as the weights or forces, and directly as the lengths of the arms, so that when, for instance, the arms are as 1 : 3, the spaces traversed will be 1 : 3. This proposition is of great importance, as it follows from it that by an elongation of the arm of the lever to which the power is applied, the effect of the lever may be increased in proportion, but that the time required for the production of a particular effect is also increased; so that what is gained in power is lost in time. Archimedes, after developing the law of the lever, was correct in saying, "Give me a fulcrum out of the earth and I will raise her from her foundations." But let us see what effort it would cost him. Supposing him to work for ten hours each day, and to exert a force of 30 pounds in pulling an arm of the lever through 10,000 feet per hour, he would, in the space of 1,473,973,790 centuries, have elevated the earth just one inch! For, let the force exerted = 30 lbs., the weight of the earth = W, and the arc described by the long arm of the lever in moving the short arm one inch = x, then $30 \times x = W \times 1$, and $x = \frac{W}{30}$; that is, to the entire weight of the earth divided by 30.

Now, supposing the earth to be a sphere of a mean radius = 3949 miles, then, since the volume of a sphere $= \frac{R}{3}(4\pi R^2)$, the earth will contain about 256,827,726,120 cubic miles. As a cubic mile of water, at the rate of 62½ lbs. to the cubic foot, will weigh 1,752,400,000 lbs., and as the mean density of the earth, according to Cavendish, is 5½ times that of water, the cubic mile of earth will weigh 5½ times this amount, or 7,638,200,000 lbs. The entire

weight of the earth in lbs. will then be 1,961,701,537,649,784,000,000 Dividing this by 30 = 65,390,051,253,772,800,000 inches=arc described by the long arm while the short arm is moved an inch. Reducing this to feet, and considering that, at ten hours per day, 3,650,000,000 feet would be traversed in a century, we shall have for the final result, 1,473,973,790 centuries as the time required to raise the earth one inch.

The wheel and axle is a simple machine which consists of a cylinder (the axle) and a wheel, both having a common axis, at whose extremity are pins or gudgeons on which the whole can turn. The power operates generally at a tangent to the circumference of the wheel, the resistance being attached to a cord around the axle. *Pl.* 16, *fig.* 33, shows the ordinary construction of the machine, where the gudgeons of the axle are at FE, turning in the parts of the frame HF and AE; the weight, W, is raised by the cord, G, wrapped about the axle, and the power is applied to the wheel, ISB, either by the cord I, or the hand-pins S, S, S. Sometimes, instead of the wheel, arms only, like spokes, are fastened to the axle, or else a winch is employed; the effect, however, is the same. The axle may be vertical, or in any other position, without changing in the least the principle of its operation. The wheel and axle is sometimes called an endless or constant lever, as it is in fact a lever on whose arms power and resistance act always normally, although the lever rotates about its fulcrum, and weights can therefore be raised to any height. In the simple lever, the space traversed by the power is always limited. A catch wheel is attached at D.

The same conditions apply to the wheel and axle as to the common lever. The radius of the wheel is the power arm of the lever, the radius of the axle is the resistance arm, and equilibrium takes place when, in the normal action of the two forces, the power is to the resistance inversely as the radii (arms of the lever) on which they act. It is evident that an increase of power is brought about either by diminishing the radius of the axle, or by increasing that of the wheel, or the winch on which the power acts. This must, however, be within certain limits, as the axle may become too thin and break, and the wheel or winch may become inconveniently large for use. Another obstacle is found in the principle, that the greater the difference between the two arms of the lever, the greater will be the space traversed by the power in proportion to that traversed by the resistance. To obviate the first difficulty, the construction represented by *pl.* 16, *fig.* 35, has been employed. The credit of the invention has been ascribed to the renowned George Eckardt, although its date is more than a hundred years before his time. Here the part A of the axle is stronger than B, and the rope, I, I′, which passes round a pulley and supports the resistance, W, is wrapped about two parts of the axle in opposite directions. When the winch, P, is turned in such a manner that the rope winds up on the stronger cylinder, at each revolution a portion of rope is unwrapped from the smaller cylinder equal to the circumference of the greater. The part of the cord wrapped up, therefore, diminishes by the difference of the circumference of the two cylinders: here the resistance or weight is to the power as the arm of the winch to the half difference of the radii of the cylinder.

A pulley is a circular disk inclosed in a case, turning about an axis passing through its centre, and provided on its circumference with a groove for the reception of a cord. Pulleys are fixed or movable.

In the *fixed pulley* (*fig.* 19), the case is stationary and attached to some object. At one end of the rope which passes over the pulley is the power, at the other end the resistance; the former must be equal to the latter; and the advantage consists only in being able to give the power any desired direction. Thus, a weight may be raised by a power acting horizontally, or vertically downwards. Pulleys of this character (fixed pulleys) occur in *figs.* 15, 16, 25, 26, 28, 29.

Movable Pulleys, as represented in *fig.* 36, are distinguished from fixed in that the case of the pulley is movable. The cord, I, is fastened to a hook, passes under the pulley AB, which carries the weight W, and is then either elevated by the power P, or, as in *fig.* 37, passes over a second pulley to be drawn up from below. In the fixed pulleys, which are properly nothing more than means for changing the direction of motion, the weight must be equal to the power; in the movable, however, another condition occurs. Here the power is to the weight as the radius of the pulley to the chord of the arc of the pulley embraced by the rope. The most advantageous case is exhibited when the two sides of the rope are parallel, and the chord equal to twice the radius of the pulley. The power is here to the weight as 1 : 2, that is, one pound of power will raise two of weight. In the double pulley, the same condition takes place, the second pulley being a fixed one, and only serving to change the direction in which the power is applied.

In a single pulley, the proportion of 1 : 2 is the only one that can be attained, even in the most favorable cases; any desired proportion of weight to power can, however, be effected by a skilful combination of several pulleys, fixed and movable. Of these combinations there are two kinds, those in which but one string is used, and those in which several are employed. *Pl.* 16, *fig.* 38, represents the first kind; *figs.* 39 and 40, the second. In *figs.* 38 and 39, the weight, W, is attached to the movable pulleys, and the power, P, acts upon the last fixed pulley: in *fig.* 40, the relation is just the reverse, without changing the operation. As in one of these combinations all the strings must be stretched equally, and all except that on which the power operates must receive their tension from the weight—this tension, however, equalling that produced by the power—equilibrium will take place when the power is to the weight as 1 to the number of strings stretched by the weight. In *fig.* 38, or the *power pulley*, the pulleys are placed one above the other, and the statical relation of the machine is as 1 : 4; in *fig.* 39, where the pulleys are not immediately one above the other, and are united by several strings, every movable pulley connected with another by a special cord doubles the power of the machine; hence it follows, that in this combination, although the weight is suspended to four pulleys only, A, A′, A″, A‴, the statical relation is as 1 : 16. The combination represented in *fig.* 40 is still more advantageous, in which the weight is fastened to the extremities of all the cords, the axis of the upper pulley alone being attached to a beam, while all the other pulleys are movable. Here, with three movable pulleys,

the weight is to the power required for equilibrium as 15 : 1; with n movable pulleys, it will be as $2^{n+1}-1 : 1$. The combination in *fig.* 43, in which the cords A, A′, A″, work obliquely, is less advantageous and convenient.

White's Pulley is represented in front by *fig.* 42, and laterally in *fig.* 41, consisting of two blocks, Q and R, of which one is fixed and the other movable. Each block has six concentric grooves, which act as so many single pulleys, the weight hanging to twelve cords, *b*, *c*, *d*,—*n*. Hence, with this number of pulleys, the relation between weight and power is 144 : 1. This combination, however, besides the slowness of movement, has the disadvantage that, from the small diameter of the lesser pulleys, the rigidity of the cords is so great as very sensibly to affect the action of the machine.

The inclined plane, as the fourth simple machine, is represented in *figs.* 44–46. AB is the base, BC the height, AC the length of the inclined plane, viewed as a right-angled triangle, up which the weight, M, is to be moved. Divide according to the parallelogram of forces, the weight, W, of M, acting vertically downwards, into two forces, one perpendicular to the direction of the inclined side of the plane, the other parallel to it; the former will be expressed by $W \cos. BAC = W \cos. \beta = W\frac{AB}{AC}$ the weight sustained by the resistance of the inclined plane, and the latter $W \sin. BAC = W \sin. \beta = W\frac{BC}{AC}$ expressing the amount of the force parallel in its direction to the inclined plane, necessary to produce equilibrium. Hence this force will be smaller as the inclination of the plane is less, or as the length of the plane is greater than its height. Should the force, as in *fig.* 46, act in a horizontal direction, or one parallel to the base of the plane, then the force, P, required to sustain the weight, W, will be $P = W \text{ tang. } BAC = W \text{ tang. } \beta = W\frac{BC}{AB}$, or the force is to the weight as the height of the plane to its base. The force is thus smaller in comparison with the weight to be sustained, as the height, BC, is smaller with respect to the base, BA; when, as in *fig.* 45, BC = AB, or BAC = 45°, then P = W, or the power is equal to the veight. Finally, if the height, BC, be greater than the base, AB, or BAC greater than 45°, the force must be greater than the weight.

The *wedge*, the fifth simple machine, is illustrated by means of *figs.* 47 and 48. It has in general the form of a three-sided prism (in the figure appearing as a triangle, ABC): upon the side AB, and perpendicular to it, a force operates in endeavoring to drive the opposite edge, C, into a body to be split, or between two bodies to be separated; or, in case this has already been done, to retain it in its place. If, upon the wedge ABC (*fig.* 48), a force operates perpendicularly to its length, DC, endeavoring to drive it out, equilibrium occurs when the power is to the resistance as the sine of half the angle included between the two sides of the wedge, or sin. α, to the sine of the angle included between the direction of resistance and the side of the wedge. The power obtained is as the cosine of the latter angle. *Fig.* 47 represents

the wedge when the force acts abnormally, or not in the direction of the length of the wedge, by which means the wedge is driven in obliquely. In this case, the resistance is to the power as radius to the difference of half the angle included between the sides of the wedge, and the angle made by the direction of resistance with the side of the wedge. In any case, the right-angled wedge may be looked upon as an inclined plane, and the isosceles wedge as the combination of two equal inclined planes. The wedge is the more powerful as the angle included between its sides is greater; it is driven in, however, more easily as this angle is less. The wedge is principally used for splitting, in which the power acts by percussion, so that, practically, no accurate calculations can be made from the principles referred to above.

The screw is merely an inclined plane wound around a cylinder. Construct a rectangle (*pl.* 17, *fig.* 1), divide two opposite sides into any equal number of equal parts, unite the points of division, 1, 2, 3, 4, &c., of the one side, with 2, 3, 4, 5, &c., of the other, by the lines *aa'*, *cc'*, *dd'*, *ee'*, and suppose the rectangle lapped around a cylinder, the circumference of whose base exactly equals an undivided side of the rectangle; then the lines *aa'*, *cc'*, *dd'*, &c., will form on the cylinder a continuous curved line, called a *screw line*, and each single winding is called a *turn of a screw*. The height of a turn of the screw is the distance between two contiguous turns, or between the two points of the screw line lying vertically one above the other (as *a*, *c*, or *l*, *m*). If, now, a prismatic body be wound around the cylinder on the screw line, it will form the winding or thread of the screw; and the whole taken together will be a *screw spindle*, or *male screw*, when the thread is on the outside of the cylinder: it is a *female* or *mother screw* when the thread is applied to the inside of the cylinder or cylindrical cavity. According as the prismatic body wound around the cylinder is a three or four-sided prism, the thread of the screw is called *sharp* (*pl.* 17, *fig.* 2) or *flat* (*fig.* 3), where A is the spindle, and Q the mother or female screw. This female screw consists of a prismatic body, DE, in whose cylindrical hole a thread, B, is situated. The male and female screws differ in the thread being applied to a cylindrical convexity for the former, and to a cylindrical concavity for the latter. The thread of the screw may have other forms than that of the three or four-sided prisms; these are, however, the most convenient and generally used.

Male and female screws can only be used in combination with each other, and even in cases where one seems to be absent (as the female of a wood screw), it is formed by the one that is present in the material itself. Strictly speaking, the screw, although always included among them, does not belong to simple machines, as it can never be applied without the assistance of a lever to turn the spindle in the nut.

In the movement of a screw three cases may present themselves: either the spindle is fixed and the nut is turned, thus advancing along the former; or the nut is fixed and the spindle moves in it; or, finally, both male and female move, uniformly, but with different velocities, often in different

directions, whence arises a retarded or accelerated differential motion; the theory remains the same, however, in all cases.

With regard to the statical condition of the screw, equilibrium takes place when the power is to the resistance or weight as the height of a turn of the thread, or the distance between two threads, is to the circumference of the circle described by the power. Hence it follows that by prolonging the lever used in producing the rotation, or by diminishing the height of the threads, the greatest resistance can be overcome by a moderate power; here, however, the universal law presents itself, that what is gained in power is lost in time.

An endless screw is a spindle containing only a few turns, which catch either in a half open female screw, cut in the circumference of a disk, or in a wheel whose teeth are placed obliquely to the axis of the wheel, and in the direction of the obliquity of the thread, or in a rack-work with similarly situated teeth. The application of the endless screw to a windlass has been selected as an illustration, and figured in *pl.* 16, *fig.* 34. Upon the axle BC, turned by the winch A, are to be found at D several turns of a screw, which, immovably fastened to the axle, turn with it without advancing. In these turns of the thread, the oblique teeth of the wheel, F, catch, thus moving along the inclined plane of the thread, and causing the wheel to turn. As there are always as many teeth of the wheel caught by the screw as the latter has complete turns, and as for the turns going out at one side, new ones are constantly entering at the other, the motion is endless. This machine, it will readily be perceived, is a combination of the screw with the wheel and axle, and its statical condition will be $P \times AB \times$ *rad.* $F = W \times$ *height of a turn of the thread* $\times$ *rad. of axle.*

The screw, in its various varieties and modifications, finds innumerable applications in machinery; we shall here briefly mention a single one, the differential screw of Hunter, represented in *pl.* 17, *fig.* 4. EF is a plate of metal in which the screw D works, having, for example, ten turns to the inch. The inside of the screw is hollow, and forms at LM a nut, in which works the smaller screw, NO, having perhaps eleven turns to the inch, and forced by the frame, EFGH, to take part in the motion of the screw, D. Suppose now that by means of the handle BC, the screw D is turned round ten times, then A will rise one inch, and will raise the point K to an equal height. Turning the screw NO ten times in the opposite direction, the point K will descend $\frac{10}{11}$ of an inch, and the result of the whole will be an elevation of $\frac{1}{11}$ of an inch. Now, however, while the screw D turns ten times, the turning of NO is hindered by the square shoulder at K, and the result is the same as if NO had been turned ten times in the other direction, and K will consequently ascend only $\frac{1}{11}$ of an inch: for a single revolution of the screw this will amount to $\frac{1}{110}$ of $\frac{1}{11}$, or $\frac{1}{1\,1\,0}$ of an inch, which is the actual ascent or descent of the screw. Suppose the length of the lever, AB, to be only six inches, then to produce equilibrium the power must be to the resistance as 1 to $110 \times 6 \times 2\pi = 4146.912$.

With respect to the simple machines, it is to be remarked, that to pro-

duce motion the applied force must be considerably greater than what is necessary for equilibrium, and this increase of power required will be in proportion to the number of obstacles to motion. Of these, the principal is *friction*, which requires a greater or less increase of power, when an actual motion of the machine is demanded. On the other hand, friction admits a diminution of power when equilibrium is to be restored after motion has taken place, or when motion is to be prevented. In the investigation of the action of machines, therefore, reference must be had to friction and similar hindrances, the rigidity of cords, &c., for example.

c. On the Strength and Stress of Materials.

When a solid body is exposed to any stress whatever, whether in the direction of its fibres, or perpendicular or obliquely to them, and this stress be continued until a fracture results, before this last circumstance occurs, there must be a moment in which there is an equilibrium between the resistance of the fibres of the body or its strength, and the stress to which it is exposed; by strength being meant the power resisting fracture, and stress the power tending to produce fracture. By reason of this equilibrium the theory of the strength of bodies comes under the head of statics.

This *strength* of bodies may be considered under three points of view: first, with regard to the *absolute* or *longitudinal strength*, or the resistance presented by a body to a force acting in the direction of its fibres, and tending to tear them apart, as in *pl.* 17, *fig.* 5; secondly, with regard to their *relative, respective*, or *transverse* strength, or the force with which a body supported or fastened at one or both ends, resists a force acting transversely, that is, perpendicularly or obliquely to the direction of its fibres; thirdly, *the strength of resistance*, or the force with which a body resists a pressure tending to crush or crumble it. By *strength of torsion* is meant the resistance of a body to a force striving to twist it about its fixed axis.

The absolute strength of two beams or rods—the form is indifferent—is in direct proportion to the area of their transverse sections. Thus if the body fastened to A (*fig.* 5, *pl.* 17) have at B a transverse section of one square inch, and be just capable of supporting the weight applied to C, then a body three inches square or nine inches in area will sustain nine times that amount. The weight of the body itself, however, must be taken into account, as acting at its centre of gravity. A rod or pole may be made so long as to break or tear asunder with its own weight, as soon as its weight acting at the centre of gravity exceeds the absolute strength of the transverse section. On this account, this centre of gravity should be brought as near as possible to the point of support, and such bodies should always be made stronger above, as in *fig.* 5.

If to a wire or any elastic body weights be suspended, not enough, however, to produce a rupture, and the extension suffered by the operation be measured, it will be found that the relation between the weight, P, and the

extension, E, may be expressed by the following general equation: $\frac{P}{P'}=\frac{E}{E'}\cdot\left(2-\frac{E}{E'}\right)$, where P′ is the weight at which the wire would tear, and E′ the extension produced by it.

However simple the theory of absolute or longitudinal strength may be, that of *relative* or *transverse strength* is exceedingly complicated. Here, not only the area of the transverse section is to be taken into account, but also the shape; and likewise, in addition to the resistance against fracture, that also to every bending of the body which may be produced by the pressure.

If a prism be supported at the two extremities, or fastened at one, and be loaded in the middle, or at the free extremity in the latter case, there will be a bending of the prism. This will take place in such a manner, that while one set of fibres will be stretched, another set will be compressed; in the interior of the transverse section, therefore, a fibre can be imagined about which this bending takes place, without experiencing itself either extension or compression; this fibre is called the *axis of flexion*, or the *neutral axis*.

Supposing the fibres of a beam to be absolutely incompressible, and the beam loaded as in *pl.* 17, *fig.* 8, at Q, then it must turn about its lower point in the line through AC, and every fibre in this direction will be in a state of tension; if all the fibres were entirely unextensible, then the rotation would occur in the same manner, but every fibre in the line would be in a condition of pressure. It is known, however, that all bodies may be both compressed and extended; therefore the rotation will be about neither the upper nor the lower point, but, as in *fig.* 6, about the point B, and the upper fibres will then be stretched, while the lower will be compressed; those in the line AB will be in a condition of neutrality. Now, both above as well as below the neutral axis, a point may be imagined, in one of which the moments of compression, and in the other of extension, are united, these being the means of pressure and tension. In *fig.* 9, let the weights, P and Q′, represent the sum of this tension and compression, then the position of the neutral axis will be determined by the ratio of the moments, and will lie in the middle when the moments are equal. The mean points of compression and extension coincide with the centres of gravity of their respective surfaces.

The mode of finding the neutral axis, and consequently the relative strength, for the case in which the body consists of extensible and compressible fibres, is explained in *fig.* 6. Imagine a body in the form of a parallelopipedon, whose breadth is *b*, and height *h*, and which is fastened in such a manner into the wall, CC, as to have in a natural condition the direction BB′. If, by a weight at A, it be bent into the position BFA, then BFA is the neutral axis. Let EF = λ be a smaller part of this axis, so that GK is an element of the body; then, in an uncompressed condition, this will everywhere be equal in length to λ. Draw JK parallel to GG′, and represent the distance, ET, of a fibre, ST, from the axis by $u = (FT)$; also make

g equal to the distance from the axis of the most extended fibre, β, then will $ST = \frac{\beta}{g} . u$, and the force q, producing this extension, will $= \frac{AE}{\lambda} . \frac{\beta}{g} . u$; here A is the absolute strength, and E the modulus of elasticity, or the weight necessary to stretch the body to double its length. GF is, however, composed of an innumerable number of fibres, whose sum, FH, may be represented by h', and the force, P, necessary to extend all these fibres will $= \frac{E}{\lambda} . \frac{\beta}{g} . \frac{bh'^2}{2}$. The compressing force, P′, for the part below the axis, whose modulus of elasticity, or force required to compress it to half its original length, may be represented by E′, will be $= \frac{E'}{\lambda} . \frac{\beta}{g} . b \frac{(h-h')^2}{2}$. The statical moments of the two forces are, $Py = \frac{E}{\lambda} . b . \frac{\beta}{g} . \frac{h'^3}{3}$ and $P'y = \frac{E'}{\lambda} . \frac{\beta}{g} . b . \frac{(h-h')^3}{3}$. The statical moments, however, of the weight Q, whose leverage, $FL = x$, will then necessarily be $Qx = \frac{B}{\lambda g} . \frac{b}{3} (Eh'^3 + E'(h-h')^3)$. Since the fibres at F experience no compression, $P + P'$ will $= O$, or $Eh'^2 = E'(h-h')^2$, Qx then becoming $= \frac{\beta}{\lambda g} . E . \frac{bh . h'^2}{3}$.

Producing GG′ and HH′, until they intersect at U, then UF will be the radius of curvature, ϱ, for the arc element, $EF = \lambda$, and $\frac{\lambda}{\varrho} = \frac{ST}{u} = \frac{\beta}{g}$ and $\frac{1}{\varrho} = \frac{\beta}{g\lambda}$: this value substituted in the formula for Qx, and φh taken for h', where φ is a magnitude dependent upon the situation of the neutral axis, and expressing the ratio of extensibility and compressibility, we will have $Qx . \varrho = E . \varphi^2 . \frac{bh^3}{3}$. The right side of this equation is constant for equal parallelopipeda, and depends upon the elasticity of the body; it is called the moment of elasticity = W. Let Q be the mean of several forces, then Qx, the sum of their moments, will = M, and $M\varrho = W$; that is, for every transverse section at right angles to a bent parallelopipedon, the product of the radius of curvature by the moment of the force, is a constant quantity.

In most cases, however, the bending of the body is so slight, that the leverage, x, of the weight Q, may be exchanged for the length, $F\Lambda = 1$, and $\frac{\beta}{\lambda} = \frac{m}{E}$: we thus obtain, by introducing this quantity into one of the preceding equations, $Q1 = \frac{m}{gE} . W$. Suppose now the body (*pl.* 17, *fig.* 6) to be fixed in the plane HH′, the preceding formulæ will give the moment of the weight, Q, which can break off the body, HDD′H′, at the plane HFH′; Q is also the relative or transverse strength of the parallelopipedon. The co-efficient of fracture, m, must be obtained by trial. Assuming the neutral

axis to pass through the centre of gravity of the surface of fracture, then $\varphi = \frac{1}{2}$, and $g = \frac{1}{2}\ h$, which gives the relative strength of the parallelopipedon, $Q = \frac{1}{b} m \frac{bh^2}{1}$. The relative strengths, therefore, of parallelopipedal bodies of the same material are as their breadths, as the squares of their depths, and inversely as their lengths. If it be necessary to consider the weight, G, and if the centre of gravity be taken at half the length, we obtain $Q = \frac{\frac{1}{6} m \,.\, bh^2}{b} - \frac{1}{2}\ G$.

As an illustration of the application of this proportion, let *fig.* 10 represent a rectangular plate, with its longer edge, AF, walled in horizontally: suppose a weight, Q, to be suspended at E, and increased until fracture ensues Required the direction of the line of fracture, BD, and the magnitude of the weight, Q. Representing the height or depth of the plate, BF, by h, then $Q = \frac{1}{6} m \,.\, \frac{BD \,.\, h^2}{GC}$. If the unknown angle, DBC, be represented by α, then $BD = \frac{BC}{\cos.\ \alpha}$, or if $tg\alpha = x$, $BD = BC\ \sqrt{1 + x^2}$; also $GC = BC \sin.\ \alpha = BC \frac{x}{\sqrt{1 + x^2}}$, and these values substituted in the equation for Q, give $Q = \frac{1}{6} m \,.\, \frac{1 + x^2}{x} - h^2$. Finding from maxima and minima, the value of x, for which the factor, $\frac{1 + x^2}{x}$, is a minimum, we learn that this is the case when $x = 1$, whence $tg\alpha = 1$, and $\alpha = 45°$: Q is then $\frac{1}{3} m \,.\, h^2$.

The strength of a beam, AB (*fig.* 12), exposed to fracture from a weight, Q, acting in a direction perpendicular to its fibres, is as the product of the transverse section at the place where the weight is applied, and the distance from the centre of gravity of the same cross-section, to the point or line where the fracture terminates. In beams of square sections, the strengths are as the cubes of the sides; in cylindrical beams, as the cubes of the diameters; in two similar beams, as the cubes of the homologous sides.

The strongest rectangular beam which can be cut from a given cylinder, is one in which the squares of the breadth, depth, and diameter of the cylinder are as 1 : 2 : 3. This beam may be found, according to *pl.* 17, *fig.* 7, in the following manner:—Divide the diameter, AE, into three equal parts at G and H; erect GF and DH perpendicularly to these points, and produce them to the circle, BC; A, F, D, and E, will determine the four corners of the beam. Here the breadth of the beam is to its depth as 5 : 7, or more accurately as 12 : 17.

The strain to which beams are exposed, under different circumstances, is determined by very complicated calculation. Let L represent the length of leverage, from the neutral axis to the point of attachment of the weight, W the weight, and α the angle made by the above-mentioned leverage with the horizon at the instant of fracture; then the strain for the case repre-

sented in *fig.* 8, will be $= LW \cos. \alpha$; for that in *fig.* 11 $= \frac{1}{4} LW \sec.^2 \alpha$, and for that in *fig.* 12, $= \frac{1}{8} LW \sec.^2 \alpha$.

The preceding formulæ have had reference to the conditions of equilibrium of beams supported at both ends and loaded in the centre; we will now consider the case where the load is applied elsewhere than in the middle, as in *pl.* 16, *fig.* 50. The weight appended may then be supposed to be divided into two weights, which act on the arms of levers whose lengths are as the parts of the beam. Thus, representing by L the entire length of the beam, m, and n its parts, then the pressure $= \frac{mn}{m+n} . W = \frac{mnW}{L}$. Supposing two equal or different weights applied at different points, as in *fig.* 51, and calling the distance from the left point of support to the left point of suspension of the weight, m; that from the left point of suspension to the right point of support, n; that from the left point of support to the right point of suspension, r; and that from the right point of suspension to the right point of support, o; then for the first weight the pressure will be $F = \frac{mnW}{L}$, and for the second $F = \frac{orW'}{L}$, where W and W′ are the corresponding weights, and L the length between the points of support. To obtain the pressure resulting from this double pressure, upon every other point of the beam, call the distance of this point from the left point of support, s, and that from the right, t, and we will have the following proportion: $n : t :: \frac{mnW}{L} : \frac{mtW}{L}$, for the pressure exerted by the left weight; and $o : s :: \frac{roW'}{L} : \frac{osW'}{L}$, for that of the right; hence the combined pressure at this third point $F = \frac{mtW + osW'}{L}$.

An application of this proposition is to be found in *fig.* 49, where the weight acts upon the middle of an inflexible bracket. Here the effect of this weight upon the beam is the same as if two weights of half the original one were suspended at the points where the bracket meets the beam. It will be easy, from the preceding, to determine the value of F in the middle of the beam, where, as in *pl.* 16, *fig.* 52, several equal weights are suspended. It also follows, that when the burden is distributed uniformly over the whole beam, its action is the same as if half the amount were attached to the centre of the beam.

The beams hitherto considered have been, for the most part, such as were supported at the ends; and we have found that such a beam is four times as strong as the same beam attached to a wall by one extremity and loaded at the other. Supposing the beam to be walled in at both ends, as in *pl.* 17, *fig.* 12, and loaded by the weight Q, we may assume that it will break at the same instant in A, B, and C, provided Q be of sufficient amount. Represent the forces which produce fracture at these three points by p p', p'', and the two parts of the beam by a, a', the total length of the

beam by L, its breadth by b, and its depth by h. Fracture will then ensue when, according to the preceding formula, $p = \frac{1}{6} m \frac{bh^2}{a}$; $p' = \frac{1}{6} m \frac{bh^2}{a'}$; and $p' = \frac{1}{6} m \frac{bLh^2}{aa'}$. Q, however, must be sufficient to produce all three fractures; therefore, $Q = \frac{1}{6} mbh^2 \left(\frac{1}{a} + \frac{a}{a'} + \frac{L}{aa'} \right)$; or, as $a' = L - a$, $Q = \frac{2}{6} m \frac{bLh^2}{aa'}$. Calling the distance by which the point, C, lies out of the centre, d, then will $Q = \frac{3}{6} m \frac{bLh^2}{L^2 - 4d'^2}$; if $d = 0$, or if C lie in the middle, then $Q = \frac{3}{6} m \frac{bh^2}{L}$. Hence it follows from this formula that beams loaded in the middle are weakest, but that they can support eight times as much as when attached at one end and loaded at the other.

For the case in which the beam, as in *fig.* 13, is inclined at an angle, as BAD $= \alpha$, to the horizon, the perpendicular lateral force, CG $= Q \cos. \alpha$, can alone tend to produce fracture; the other lateral force, CF $= Q \sin. \alpha$, involving the strength of crushing: Q becomes then $= \frac{1}{3} m \frac{bLh^2}{aa' \cos. \alpha}$.

Those bodies which in all their sections present the same strength are of great importance: *the bodies of equal resistance.* The fracture of bodies of equal section throughout occurs always at the surface of attachment, or where the weight is attached; consequently the transverse sections lying at a distance from these points are too great, and must be diminished. Such a case has been considered (*fig.* 5) under the head of absolute strength; it remains here to mention some others. *Fig.* 14, *pl.* 17, represents a body which, fixed at one end, is loaded at the other with the weight Q, and where transverse sections are throughout, rectangles of equal breadth: representing the height by y, the breadth by z, and the distance from C of the section MN by x, then, according to the preceding nomenclature, AB $= h$, AC $= L$, and $z = b$: we then have $\frac{bh^2}{L} = \frac{by^2}{x}$, hence $y^2 = \frac{h^2}{6} . x$. This, however, is the equation of the parabola; and the outline, BC, must be a parabola, whose vertex lies at C, and whose parameter $= \frac{h^2}{6}$. *Pl.* 17, *fig.* 15, represents a similar body, ABC, upon which the weight, Q, is uniformly distributed. Here the same references are employed, and we have for y in the section MN, the value $y = \frac{h}{L} . x$, whence it follows that the outline, BC, must be a straight line. Finally, suppose *fig.* 16 to represent the body, AB, resting freely at its two extremities, its sections rectangles of equal breadth, and the weight, Q, moving longitudinally above the body; required the conditions according to which the inferior curve line is formed. Let AC $=$ BC $= \frac{1}{2} L = a$, CD $= h$, and for any given section, MN, CM $= x$, and MN $= y$; then $y^2 = \frac{h^2}{a^2} (a^2 - x^2)$, and the curve of outline will be a

semi-ellipse, whose semi-major axis is a, and semi-minor axis $= h$. Should the least height not equal 0, but a quantity, $CC' = c$; then if M'N be taken $= y$, and $MN = y'$, $y' + c$ will equal the height, and the equation becomes $(y' + c)^2 = \frac{h^2}{a^2}(a^2 - x^2)$; and for the points, A and B, beyond which the height remains unchanged, where y' thus $= 0$, we will have $x = \frac{a}{h}\sqrt{h^2 - c^2}$.

It is often desirable to determine the amount of flexion which precedes the fracture of any elastic body; in this case it is necessary to determine the shape of the elastic line formed by the neutral axis. Suppose (*fig.* 17) BZ to be the natural condition of a fibre attached at one end, B, and this fibre loaded at A by Q, and uniformly along its whole length by a weight, which, for a single unit of length, amounts to p; the fibre takes the form of the elastic line, AB. Let AC be the axis of abscissas, A the origin of co-ordinates, and for any given point, E, of the curve, whose radius of curvature is ρ, take $AF = x$, $FE = y$, the greatest ordinate, $BC = u$, and $AC = a$; let W also be the moment of elasticity, and for the elastic line we will have the co-ordinate equation, $y = \frac{Qx}{2W}(a^2 + \frac{1}{3}x^2) + \frac{px}{6W}(a^3 - \frac{1}{4}x^3)$, and the greatest ordinate, u (where $x = a$), $= \frac{Qa^3}{3W} + \frac{pa^4}{8W}$. If $p = o$, or the fibre be loaded only at the end, then will $u = \frac{Qa^3}{3W}$, and $y = \frac{Qx}{6W}(3a^2 - x^2)$; and if $Q = 0$, or the fibre be loaded only uniformly along its whole length, $u = \frac{pa^4}{8W}$, and $y = \frac{px}{24W}(4a^3 - x^3)$. According to the above formulæ, the co-ordinates are as 8 : 3, thus the depression is much greater when a weight hangs at the extremity of the fibre, than when it is distributed along its whole length.

If the elastic fibre rest, as in *fig.* 18, at both ends, the weight Q being applied in the middle, the equations answering to these conditions result from the preceding. Let Q be the weight applied to the middle, pL that distributed along the whole length, L; then each support receives a pressure $= \frac{1}{2}(Q + pL)$. Suppose, however, the fibre to be fastened at C, and the pressure at A and B to act upwards, then, in the preceding co-ordinate equation, $\frac{1}{2}(Q + pL)$ must be substituted for Q: the second part of that equation must be taken negatively, as it contains p as a factor, and this must necessarily act vertically downwards, or in the opposite direction to $\frac{1}{2}(Q + pL)$. As, moreover, $\frac{1}{2}L = a$, we obtain the new co-ordinate equation $y = \frac{(Q+pL)}{4W}\left(\frac{L^2}{4} - \frac{1}{3}x^2\right)x - \frac{px}{6W}\left(\frac{L^3}{8} - \frac{1}{4}x^3\right)$. The greatest ordinate, also, when $x = \frac{1}{2}L$, becomes $u = \frac{L^3}{384W}(8Q + 5pL)$. If $p = 0$, then $y =$

$\frac{Q}{4W}(\frac{1}{4}L^2-\frac{1}{3}x^2)x$, and $u=\frac{QL^3}{48W}$; if Q again $=0$, then will $y=\frac{px}{24W}(L^3-2Lx^2+x^3)$ and $u=\frac{5pL^4}{384W}$. Assuming $Q=pL$, then the depression in the two cases will be as 8 : 5; consequently, when a weight is distributed uniformly along the whole fibre, the depression will be only $\frac{5}{8}$ of what would result from the application of the same weight to the middle.

In investigating the strength of resistance to a crushing force, we suppose prismatic bodies standing vertically, upon whose upper extremities weights are laid, and then investigate the force necessary for crushing, and that which produces first a bending, and then a cracking. With respect to the force of crushing, it appears, from experiment, to increase in a somewhat greater ratio than the cross section, although it may be properly assumed that if all parts of the cross section experience equal pressure, the force will be proportional to the cross section. Calling, therefore, the strength (obtained by trial) of a certain cross section, m, and the area of the prism to be investigated, A, then $Q=mA$. The capacity for being crushed diminishes as the circumference increases, the area remaining the same; it is, therefore, least in the circle: it is less, also, as the form of the body approaches in height to the cube.

To obtain the law of cracking, let us suppose an elastic rod, AB (*pl.* 17, *fig.* 19), which, fastened at A, assumes naturally the vertical direction AZ; becoming bent, however, into the curve ADB by a weight attached to the upper end, B. To find the co-ordinate equation of this curve, assume the vertical direction, BC, of the weight as the axis of abscissas, and B as their origin. For any point, D, of the curve whose radius of curvature is ϱ; let $BQ=x$, $DQ=y$, and $AC=a$, and let the curvature of the rod be so slight that the abscissa may be exchanged for the length of the arc. If, now, y be the leverage of Q, then $M=Qy$, and $Qy=\frac{W}{\varrho}$. By assuming another point of the curve, F, infinitely near to D, and bringing into the calculation the quantities FH, DH, with their trigonometrical proportions, we finally obtain for x the value $\sqrt{\frac{W}{Q}}$ arc. $\left(\text{sin.}=\frac{y\sqrt{Q}}{\sqrt{Qa^2+Wtg\varphi^2}}\right)$, where the one factor is an arc whose sine is equal to the quotient of the two radical quantities, φ indicating the angle at which the geometrical tangent of the point A meets the curve. For y we have the value $\frac{\sqrt{Qa^2+Wtg\varphi^2}}{\sqrt{Q}}\text{sin.}\sqrt{x\sqrt{\frac{Q}{W}}}$. Most generally a is to be taken $=0$, or the direction of the bending weight passes, as in *pl.* 17, *fig.* 20, through the point of attachment, A. The equation then becomes $x=\sqrt{\frac{W}{Q}}\text{arc.}\left(\text{sin.}=\frac{y}{tg\varphi}\sqrt{\frac{Q}{W}}\right)$, and $y=tg\varphi\sqrt{\frac{W}{Q}}\text{sin.}\left(x\sqrt{\frac{Q}{W}}\right)$.

For the points A and B, $y=0$, thus $x=\sqrt{\frac{W}{Q}}$ arc (sin. $=0$); as, however, arc (sin. $=0$) may be taken $=0, \pi, 2\pi, 3\pi - - - i\pi$, where i represents

any whole number, it follows, if L represent the length of the rod $= x$, that $L = i\pi\sqrt{\frac{W}{Q}}$, and if $i = L$, $L = \pi\sqrt{\frac{W}{Q}}$, and $Q = \frac{\pi^2 W}{L^2}$. As, however, Q is independent of the amount of the bending, this weight, in any degree of bending, holds the elasticity of the body in equilibrium, or Q is the capacity of cracking of the rod.

Combining these values with those previously obtained by substituting the moment of elasticity for W, we find that in prismatic beams of homogeneous material, the capacities of cracking are as the breadths, as the third power of the thicknesses (least sides), and inversely as the squares of the lengths; in cylinders, as the fourth powers of the radii, and inversely as the squares of the lengths.

With respect to the *strength of torsion*, or twisting, let us suppose a body (*fig.* 21, *pl.* 17) fixed at one of its ends, AA′, and a force, P, acting at the other extremity on the arm of a lever, CD = R, capable of producing a rotation about the axis, CC. If, now, the diameter BB be twisted to B′B, AA′ will be stationary; the homologous diameters, however, of all intermediate sections will be displaced in proportion to their distance from the surface of attachment. The angle BCB′ is then the angle of rotation, and the turning force must be strong in proportion to the amount of this angle, to the strength of the transverse section of the fibres, and to the distance of the fibres from the axis of rotation; the longer the fibres, however, the less need be the force.

An actual twisting apart of the body must ensue when the remote fibres can yield no more without being actually ruptured; and in cylinders of homogeneous material, the statical moments of the forces which produce such a rupture by twisting, are as the cubes of the radii.

B. Dynamics of Solid Bodies.

The theory of motion is much more difficult as well as more comprehensive than that of equilibrium: it calls mathematics into play to a much greater extent, and this in its most abstruse branches.

The motion of a body, which may result from one or several forces, is, in respect to its direction, either rectilineal or curvilineal; in respect to its velocity, either uniform or variable. Motion is said to be *equable* when equal spaces are traversed in equal times: when, for example, the same amount of space is passed over in each successive second. Of this kind is all motion produced by a single force acting instantaneously—in a blow, for instance—provided that the motion meet no obstruction. Motion is *variable* when, instead of remaining the same, it increases or diminishes. If the motion increase or diminish equally in equal times, it is said to be *uniformly accelerated* or *retarded.*

Tne force itself producing motion may be either momentary or continuous. In the former the force is to be considered as acting for a very

little, or no time at all; in the latter the action takes place incessantly without a conceivable instant in which the force does not exert its influence. Every momentary force imparts to a material point upon which it operates an equable motion; every continuous force operates in producing an accelerated or retarded motion.

The following may be adduced as fundamental propositions in Dynamics, consequently not derived *à priori*, but the results of experience. They are modifications of the well known Newtonian laws of motion.

1. A moving material point continues in a state of rectilineal and equable motion, until affected by some other influencing force.

2. Two forces acting momentarily, are as the velocities which they communicate to the same material point in the same instant of time.

3. A moving body loses just as much motion as it communicates to another body; that is, action and reaction are equal and opposite.

a. Equable Motion.

As a material point or body, in a condition of equable motion, traverses equal spaces in equal times, the spaces traversed in different times are as these times. If, therefore, s be the space traversed in a time, t, and s' that traversed in a time, t', then $s : s' :: t : t'$; and if $t' =$ one second, s' is the velocity, c, of the body; thus $s = ct$, $c = \frac{s}{t}$, and $t = \frac{s}{c}$. Thus in equable motion the space described equals the product of the time by the velocity; the velocity equals the space divided by the time; and the time equals the space divided by the velocity.

If a body be acted upon by two momentary forces in different directions, the direction and velocity of the motion will take place as the diagonal of the parallelogram of forces. Representing the velocities of the forces by c and v, and the included angle by α, then the velocity attained, $x = \sqrt{c^2 + v^2 + 2cv \cos. \alpha}$, and the corresponding parallelogram is called the *parallelogram of velocities*. From this it may readily be shown how much a body loses in velocity by moving with a given velocity against a fixed obstruction, and from it, it also follows, that an equably moving body which enters in the direction of the tangent upon a curve, must move in it with undiminished velocity.

b. Varying Motion.

It has been already observed that varying motion may be uniformly so or not. Taking first into consideration the *uniformly accelerated* motion of a body, the velocity after the expiration of any period of time (the final velocity) may easily be determined. In this case the velocity increases equably in equal times. If, therefore, G be the velocity at the expiration

of the first second, the acceleration for the following seconds becomes 2G, 3G $---$ tG, and the final velocity is V $= t$G.

To determine the space, s, traversed by the body in the time, t, suppose t to be divided into infinitely small portions, and let the force operate only at the commencement of one of these divisions; if then the number of the divisions observed $= n$, and the velocity at the end of the first division, $\frac{t}{n}$ $=$ W, then the space traversed in the different divisions $=$ W $\frac{t}{n}$, 2 W $\frac{t}{n}$, $---$ n W $\frac{t}{n}$, and $s =$ W $\frac{t}{n}$ $(1 + 2 + 3 --- + n)$. If n be infinitely great, then $s =$ W $\frac{tn^2}{2n} = n$ W $\frac{t}{2}$, and as nW must be the final velocity, v, of the motion, $s = \frac{vt}{2} = \frac{\mathrm{G}t^2}{2}$, and $t = \sqrt{\frac{2s}{\mathrm{G}}}$. From these investigations the following propositions respecting uniformly accelerated motion may be developed:—1, the final velocities attained at the expiration of different times are as these times; 2, the space described during uniformly accelerated motion, is half that which would be described if the motion had been equable and of the final velocity; 3, the spaces traversed are as the squares of the times which have expired during the motion; 4, the spaces traversed in successive equal times increase as the odd numbers, or as 1, 3, 5, 7, &c.

The laws of uniformly varying motion may also be presented geometrically. Suppose the body to begin its motion from a state of rest at A (*pl.* 17, *fig.* 22); draw the straight line, AB, marking off upon it the equal parts, Aa, ab, bc, and erecting the ordinates aa', bb', cc', at the points of division. The abscissas, Aa, Ab, Ac, then represent the time elapsed since the beginning of the motion, and the corresponding ordinates, the final velocities. As these are all proportional to the aforesaid time, it follows that the line, AC, joining the ends of the ordinates, must be a straight line. Assuming the distances Aa, ab, bc, &c., as infinitely small, and drawing to AB the parallels $a'b''$, $b'c''$, $c'd''$, &c., small right-angled triangles result, whose sides, $b'b''$, $c'c''$, give the successive increase of velocity. The surface of the corresponding trapezoid has always an equal numerical value with the length of the path described by the accelerated motion; consequently the sum of all the trapezoids plus the small triangle, Aaa', or the surface, Ahh', represents the entire space traversed from the beginning. This triangle, however, is half the size of the rectangle which serves as the measure of the space traversed in equable motion, hence follows the proposition (No. 2) adduced above.

The laws of the *unequably accelerated* motion of bodies present many difficulties in their development. Suppose, in the first place, that it be desired, from the observed unequably traversed spaces and the corresponding times, to determine the velocity at the different points of the path described. To this end let AB (*pl.* 17, *fig.* 23) represent the axis of abscissas, AC the axis of ordinates of a system of rectangular co-ordinates, and A the starting point of

motion; the times may be taken as abscissas, the spaces traversed as ordinates. Assuming the parts Aa, ab, and c, of the axis of abscissas as infinitely small, then the line Ad connecting the extremities of the ordinates, a', b', cannot be a straight line, but must be curved; the small triangles, $a'b'b''$, $b'c'c''$, must also be unequal; consequently, the velocity of motion must change at every moment. Suppose, furthermore, that at any instant of motion, corresponding to the point c', this motion suddenly becomes equable, then this new motion will be represented by a straight line, $c'E$, the prolongation of the chord of $c'd'$. As, moreover, the moving point in the instant when the motion is considered, during the elementary time $c'd''$ or cd, would have described the space $d'd''$, it will by reason of the ensuing equable motion describe a space in the unit of time, determined by obtaining the ordinate mn for $c'm$ and $c'n$; the space mn then serves as the measure of velocity for uniform motion, and is thus the final velocity desired.

c. Freely Falling Bodies and Projectiles.

The theory of freely falling bodies is a consequence of the preceding propositions respecting uniformly accelerated motion. The force of gravity which here comes into account, must, if the motion be uniformly accelerated, be a constant force. It is known, indeed, that the intensity of this force diminishes as the square of the distance from the centre of the earth; as, however, the greatest space which can be traversed by a body is extremely minute, compared with the earth's radius, it will involve no serious error to consider the action of gravitation within these limits as a constant force. The weight of the body is not taken into account in determining the laws of free falling, as gravitation acts uniformly upon all the atoms of a body, and although practically, weight does seem to be of account, the reason of this lies in the resistance of the atmosphere: all bodies fall with equal velocity in a vacuum.

In the free falling of bodies, the two propositions may be brought into application—that the velocities of a freely falling body are constantly proportional to the time expired, and that the spaces are as the squares of the times. It becomes necessary to determine the acceleration produced by gravitation, that is, the value of the space fallen through at the end of the first second, which can only be done by direct experiment. From carefully conducted experiments, it has been found that at a mean geographical latitude, and a height not too great above the level of the sea, the acceleration amounts to 9.81 metres (31 feet, 11 inches, 11 lines, English; 30′ 2″ 7‴, French; 31′ 3″ 2‴, Rhenish). Calling this acceleration g, the body in the first second traverses $1\frac{g}{2}$; in the second, $2^2\frac{g}{2}$; in the third, $3^2\frac{g}{2}$; and the entire space, s, fallen through in t seconds is $t^2\frac{g}{2}$.

Atwood's machine is best adapted to demonstrate the correctness of results obtained by these investigations. The entire instrument is figured in *pl.* 16, *fig.* 17; *fig.* 18 represents its upper portion on a larger scale.

The machine consists of a post, F, about 7 feet high, with its base, S, capable of being rendered perfectly vertical by the four adjusting screws; on its upper end there is a frame, T, carrying the proper apparatus. This apparatus consists of a wheel, K, united to the axis by the spokes, *a*, *b*, *c*, *d*, and over which runs a string to which hang the weights, A and B. Each end of the axis rests in the angle of two overlapping friction wheels, L, M, and N, O, so that the friction wheels taking part in the motion of the main axis, reduce the friction to its minimum. A divided scale, G, is fastened to the foot by the clamp, R, and upon this scale the two shifting platforms, H and C, may be fastened at pleasure by screws. The clock, D, attached to the post, F, indicates seconds, thus serving as a measure of the times of falling.

As the weights, A and B, are perfectly equal, they will be in equilibrium when attached to the two ends of the string passing over the wheel, K. This equilibrium will, however, be disturbed when an extra weight, *n*, is laid upon one of them, the heavier weight falling, and the lighter rising with accelerated velocity. As the motion of the two weights is entirely the result of the extra weight laid upon the one, it takes place slower than in a freely falling body, and this retardation of velocity is in the same proportion which the extra weight, or the difference of the two weights, bears to their sum; it takes place, however, as to the rest, according to the laws of freely falling bodies. Thus, if *m* indicate each one of the originally equal weights, and *n* the superimposed extra weight, then the velocity and the space fallen through for any given interval of time, is only $\frac{n}{2m+n}$ of the velocity and the interval of time, which takes place in the same time in a free fall. If, for example, $m = 7$oz., and $n = 1$oz., then the space traversed in the first second is only 1 foot, that in the second, 2 feet, in the third, 3, &c.; and by diminishing *n* in proportion to *m*, the motion may be rendered as slow as may be desired. To measure the space fallen through, the scale, G, is divided off into fractions of inches; the two platforms may be attached to any part of the scale, and of these the upper has a hole large enough to allow the passage of one weight after the removal of the small bar, I. If the extra weight, *n*, be so adjusted that $\frac{n}{2m+n} = \frac{1}{180}$, or more precisely, that the space fallen through in one second shall be equal to one inch; if furthermore it be so arranged as to pass through the upper platform, and if the lower one be placed successively at a distance of 1, 4, 9, 16, 25, 36, 49, 64 inches below the 0 of the scale, then the weight will be heard to strike this lower platform after successive intervals of 2, 3, 4, 5, 6, 7, 8 seconds, agreeably to the theory. If again the extra weight be so adjusted as not to pass through the upper shifter, then the descending weight, from the moment of separation from the extra weight, will continue its motion with an equable velocity. Furthermore, as in this case the accelerating force, namely, the extra weight, *n*, ceases to act, it will be found by placing the upper platform at a distance of 1, 4, 9, 16 inches beneath the zero point, and

adjusting properly the lower one, that the velocity attained amounts to 2, 4, 6, 8 inches in a second; being thus uniform.

The laws already developed serve for the vertical motion of a body; new ones must be obtained when the motion takes place in vacuo, in a direction forming any angle with the horizon. Starting then from the point of view, that all material points of the same body receive an equal progressive motion, it will be possible to restrict our attention to the laws of a single point of a body.

Suppose (*pl.* 17, *fig.* 24) A to be the starting point, and AC the direction in which the body is thrown, this would move with equable velocity in the direction AC, if unacted on by gravitation. This, however, incessantly solicits it in a vertical direction, downwards, so that after one second it would be about 16 feet; after two seconds, 4.16, or 64 feet; after three seconds, 9.16, or 144 feet lower down than if this gravitation did not act.

Calling the initial velocity a, and the angle, CAB, which the original direction forms with the horizon, α, then the projected body under the simple influence of the initial force, would in t seconds traverse the path, $t \cdot a$. and have reached the height $t \cdot a \cdot \sin. \alpha$. The force of gravity diminishes this height by gt^2, and the formula becomes $t \cdot a \cdot \sin. \alpha - gt^2$. It is evident that after a time the ascent of the body will change into a descent, and will finally return to the same horizontal plane from which it started. This takes place when $t \cdot a \cdot \sin. \alpha - gt^2 = 0$, or $gt^2 = t \cdot a \cdot \sin. \alpha$, or after $t = \frac{a \sin. \alpha}{g}$ seconds. In the middle of this interval of time, or after $\frac{a \sin. \alpha}{2g}$ seconds, the body will have reached the highest point of its path, whose height amounts to $\frac{a^2 \sin. 2\alpha}{4g}$. The line of projection is therefore a pure parabola. The rectilineal distance of the point where the body again reaches the horizontal plane, from the point where it started, or the distance of projection, is $= \frac{a^2 \sin. 2\alpha}{2g}$; it is greatest when $2\alpha = 90°$, or $\alpha = 45°$; that is, when the body is projected at half of a right angle to the horizon.

The theory of projectiles comes most into play in artillery, where it is desirable to determine, not only the path of the projectile in the air, but also the variation of range of the guns with the variation of the angle of elevation. It does not come within the province of this work to adduce to any extent the comprehensive calculations and investigations necessary to determine these paths; a few examples only are given of the modes of ascertaining the lengths and greatest ordinates of the parabola in different cases. Thus, *pl.* 17, *fig.* 25, shows how the parabola is determined when the axis of abscissas of the projectile line AE, is horizontal, and the direction of discharge deviates from the perpendicular, AB, where then the greatest ordinate passes through the vertex, D, of the parabola. In *fig.* 26 the projection takes place from a height to a depth, the gun standing at A; the greatest ordinate is EB; the line of abscissas, AB, being no longer horizontal,

and there being no angle of elevation, the descending branch of the parabola alone presents itself. *Fig.* 27 represents, by comparison with the projection in the plane, AF, the case where, to attain a greater range, AE, a projection to a lower level takes place with an angle of elevation, BAD; *fig.* 28 shows, in its left hand side, the diminution of range with a greater elevation; the right hand exhibits much the same case as in *fig.* 26.

The preceding remarks are in all strictness to be taken with regard to projection in a vacuum, which, however, never occurs in practice. The resistance of the atmosphere, in which all bodies move which are projected from the earth, changes not only the path but the velocity of projectiles, and is very difficult to calculate accurately; only very dense masses, as balls of lead, iron, &c., approach in their motions to the laws of projection in vacuo, and this indeed in proportion to their size. The range in air is 5 to 10 times less than in vacuo. The greatest range is attained by a much smaller angle than 45° (in cannon even at 20°); the highest point of the path is nearer the end than the beginning; the descending part of the path is therefore much steeper than the ascending.

d. Centrifugal Force.

In the preceding remarks it was assumed that the directions of gravitation, in all points of the path of a projectile, were parallel to each other. This is no longer the case, however, when we come to consider the motion of a body about an attracting point, as, for instance, in the motion of the earth or of any other planet about the sun. In such motion (central motion) two forces are to be imagined as operating: the centripetal force, which incessantly solicits the moving body towards the attracting centre, and the tangential force, which, if the centripetal force were to cease its action, would impel it outwards in a straight line in the direction of the tangent. It depends upon the proportion between these two forces whether the body is to move in an ellipse or in some other curve.

If a ball fastened to the end of a string be whirled around, the string experiences a tension which increases with the velocity of rotation. The cause of this tension is called the centrifugal force. It always acts wherever rotation takes place about an axis, and consequently in the rotation of the earth on its axis; at the equator it is greatest, as here the velocity of rotation is greatest, and opposed to the force of gravitation; at the poles it is zero. In experiments upon the centrifugal force, the apparatus represented in *fig.* 29, *pl.* 17, may be employed, called a *centrifugal machine.* By means of the winch, *d*, the horizontal disk beneath it is rotated, this rotation being communicated by a string, *e*, to a second disk of smaller radius; this latter disk must turn the quicker as its radius is less. With it, and in the continuation of its axis, turns the vertical axis, *c*. If a thin ring of brass be fastened to the lower end of this axis, the upper curve capable of moving freely up and down the axis, this ring, if circular when at rest, will assume an elliptical shape when in motion, and the shape will deviate

more and more from that of the circle, in proportion to the increase of the velocity.

e. Of the Pendulum.

A body which is capable of oscillation about an axis, neither vertical nor passing through the centre of gravity, is called a *pendulum*. Suppose (*pl.* 16, *fig.* 20) a material point, B, to be attached in such a manner to the extremity of a weightless line, AB, that the line can swing freely about the other extremity, A, we shall have a simple or mathematical pendulum; and the combination of a small heavy sphere with a thin thread, to which it is suspended, may be regarded without serious error as a simple pendulum. If such a simple pendulum be brought from its vertical position, AB, which, from the laws of statics, it must assume, into the position, AB′, and left to itself, it will, by reason of the attraction of gravitation, be brought back towards B, and describe the arc, BB′, lying in the same plane with AB. It will arrive at B with a velocity corresponding to the depth of fall, that is, to the segment of the radius, AB, obtained by letting fall a perpendicular from B′ upon this radius. With the velocity thus attained, the resistance of the atmosphere and of friction being now left out of the question, the material point will endeavor to continue its path in the arc, BB″, on the other side of B, until this velocity previously attained has become zero. This point is evidently at B″ when BB″ = B′B. At B″ the same state of things occurs as at B′, and the pendulum must incessantly perform equal oscillations in the arc, B′BB″. In descending the velocity must constantly increase, and in ascending decrease, being greatest at the point of equilibrium or the lowest point of the arc. The motion of the pendulum from B′ to B″, is called the oscillation; that part of it from B to B′ or B″, is the ascending semi-oscillation; and from B′ or B″ to B, the descending semi-oscillation. The *amplitude* is the arc corresponding to the oscillation expressed in degrees, minutes, and seconds: the time necessary to describe this arc is the *duration* of the oscillation. The fact that in the material pendulum, the duration and amplitude of the oscillation continually decrease, results from the friction at the point of suspension and the resistance of the atmosphere. The pendulum being thus retarded, cannot reach the height, B″, and the altitude attained becomes less and less at each successive oscillation.

The laws of oscillation for the pendulum are as follows:—1. The duration of minute oscillations is independent of their amplitudes; they are isochronous; and a pendulum swings through an arc of 5° in neither greater nor less time than through an arc of 1°. 2. The duration of an oscillation is independent of the material and the weight of the ball, one of lead moving no faster than one of cork. 3. The oscillations of two unequal pendulums are to each other as the square roots of their lengths.

When it is said as above that the weight of the pendulum has no influence upon the duration of oscillations, it is to be understood as applying only to

an individual place: if the pendulum be carried to some other place on the earth's surface, where the intensity of gravitation is different, the duration of its oscillations will be changed.

The preceding laws apply only to the mathematical pendulum, and as these cannot actually exist, our investigations must have reference to the compound pendulum. Suppose in some point of the line AB, a molecule, m, and in B the molecule n, then m, being nearer to the point of suspension, will make shorter vibrations than n, and will consequently accelerate its motion, while n will retard the motion of m; oscillations will therefore result, such as would be produced by a simple pendulum shorter than AB and longer than Am. In every material pendulum, therefore, there must be a point whose motion is neither accelerated nor retarded by the rest of the mass, and which will consequently oscillate in the same manner as a simple pendulum whose length is equal to the distance of this point from the point of suspension. This point is called the *centre of oscillation* of the pendulum, and when mention is made of the length of a pendulum, by it is always to be understood the distance from the point of suspension to the centre of oscillation. In very long pendulums composed of very thin threads and very heavy balls, the centre of oscillation lies at an inappreciable distance below the centre of gravity of the ball attached; this centre of gravity, therefore, may without material error be considered as the centre of oscillation.

From the preceding considerations it follows that from observation of the oscillations of one pendulum, it becomes possible to determine the length of another which shall vibrate exact seconds. Borda used a pendulum which was exactly twelve Paris feet in length, and made 1876 oscillations in an hour. Now, as a seconds' pendulum must make 3600 oscillations in the same time, and the lengths of the pendulums must be as the squares of the times of oscillation, it follows that $3600^2 : 1876^2 :: 144 : x$; therefore $x = \frac{144.1876^2}{3600^2}$ = 39.14 Paris inches; more accurately, in English inches, 39.12851. The length of the pendulum vibrating seconds at New York is 39.10153 inches.

If a pendulum could be so constructed as to accomplish its oscillations in the arc of a cycloid instead of a circle, the length of the pendulum being equal to the diameter of the generating circle, all its oscillations would be perfectly isochronous; the cycloid possessing the property that great and small arcs are traversed in equal times. Huyghens, who probably first applied the pendulum to the clock, endeavored to make the pendulum vibrate between cycloidal plates or cheeks, so that the thread or spring supplying the place of the rod of the pendulum, would be obliged to bend along these cheeks; the ball moving, therefore, in a cycloidal curve, and describing isochronous oscillations. Nevertheless, the arrangement of these cycloidal plates is attended with great difficulties, and for this reason it is generally the custom to employ circular pendulums of small amplitude, which have the same advantages as the cycloidal, and are of much more easy construction. *Circular* or *centrifugal* pendulums are those in which the oscillations, instead of being performed backwards and forwards in the same vertical

arc, take place in a horizontal circle, and always in the same direction. To this end, however, the pendulum rod must be capable of moving about the point of suspension, not in a single plane only, but in any direction at pleasure.

In the material pendulum there is still a circumstance which affects the oscillations, namely, the influence of temperature, which, when elevated, lengthens the pendulum, and when lowered, shortens it. This circumstance is especially injurious not so much in particular experiments, where the length may be regulated each time, as in the application of the pendulum to clocks, where the slightest variation in its length must affect the rate. In this latter case the pendulum, to be an accurate regulator of motion, must first regulate itself; and to this end, many combinations have been devised, of which *Harrison's compensation or gridiron pendulum*, and *Graham's mercurial pendulum*, will alone be mentioned here.

The *gridiron pendulum* (*pl.* 16, *fig.* 21) was invented in 1725 by Harrison, for which, in connexion with his chronometer, he received a premium of £25,000 sterling from the British parliament. It consists of five steel and four brass rods, which alternate with each other, so that the central rod to which the disk of the pendulum is attached, is of steel. These brass and steel rods are so fixed in the heads, *aa*, *bb*, that while the expansion of the steel rods produces a tendency to elongation in the pendulum, that of the brass rods, which press upwards the head to which the pendulum rod is attached, produce a tendency to contraction. If, now, the lengths of these brass and steel rods are to each other in the proper proportion of their coefficients of expansion, or as 61 : 100, the expansion of one set will elevate the pendulum just as much as it is depressed by the other, and the actual length will be invariable.

This pendulum, philosophical and beautiful as it is in theory, is diminished in practical value by the following considerations: 1. That it is difficult to make the rods sufficiently accurate; 2. It is difficult to give them their proper proportional lengths; 3. That it is more exposed to the resistance of the atmosphere. Other metals may be employed instead of steel and brass.

The *mercurial pendulum* (*pl.* 16, *fig.* 22) invented by Graham in 1715, has a brass rod, *aab*, which carries below a cylindrical glass vessel from 13—14 inches long, and two inches in diameter. This vessel, *o*, filled up to 12 inches with mercury, forms the ball of the pendulum, and lest the expansion of the rod should be too great for that of the ball, the quantity of mercury in the latter may be varied. By the influence of temperature, the rod is expanded; the mercury is expanded at the same time, however, and its centre of gravity is elevated: the pendulum is thus shortened again, and by trial a very accurate compensation may be obtained. The single influence operating against this pendulum is that the mercury sometimes begins to expand before the rod; the variation, however, rarely amounts to more than one eighth of what takes place in good common pendulums. The disk, *d*, serves for the general regulation of the pendulum.

After Galileo had developed the laws of the pendulum, Huyghens determined the centre of oscillation of the material pendulum, and thereby made possible an accurate measurement of time, by applying the pendulum to the

regulation of the clock. Newton, however, first announced the proposition, that the same pendulum, in different places on the earth's surface, must make different oscillations. The astronomer, Richer, who journeyed to Cayenne in 1672, verified this observation, as the difference of the rate of a clock at Paris and Cayenne required a shortening of the pendulum by $1\frac{1}{4}$ line. By means of accurate experiments it was afterwards found, that for the different latitudes of St. Thomas (0° 24′ 41″) and Spitzbergen (79° 49 58″), the length of the pendulum varied from 39.021 and 39.215 Paris inches (more accurately in English inches, and reduced to the level of the sea, 39.02074 and 39.21469).

Even if the highest mountains and the deepest seas produce no change in the general form of the earth, by reason of their small size compared with the earth's radius, yet the rotation of the earth on its axis must theoretically cause a heaping up of its mass at the equator, and a flattening at the poles, so that the earth, instead of being a sphere, must be really an oblate spheroid. Measurements of degrees of the meridian have determined the amount of this oblateness. If, for example, Dunkirk and Formentera lie nearly on the same meridian, and their distance from trigonometrical measurement amounts to 1374438.72 metres (the angular distance being 12° 22′ 14″), it becomes easy to determine the length of one degree of the meridian. If now the earth were a sphere, all degrees of the meridian would be equal. Measurements of degrees in different latitudes, however, have shown that this is not the case, but that the length of a degree of the terrestrial meridian continually decreases from the poles to the equator; the radius of the equator accordingly amounts to 6,376,984 metres, and that of the poles, 6,356,324; a difference of 20,660 metres. The mean radius of the earth corresponds to that of latitude 45°, and amounts to 6,366,745 metres. The length of the pendulum is in strict relation to these measurements, for the seconds' pendulum is shorter, the nearer the place of observation to the equator, so that the seconds' pendulum of Paris would make 126 oscillations less in a day, at the equator. Hence it follows that the intensity of gravity diminishes with the distance from the centre of the earth, and experiments with the pendulum, carried on at different heights above the level of the sea, confirm this statement.

Considering that the centrifugal force increases towards the equator, and that nearer the equator the distance from the centre is greater, it becomes possible, knowing the length of a seconds' pendulum at Paris, to determine that for any other place on the earth's surface; here, however, the greater or less density of the earth's crust comes into account; as it is found that there are always slight discrepancies between the calculated and actual pendulum lengths—differences which may sometimes amount to four or five oscillations in a day. To this belongs the deviation experienced by the plummet in the vicinity of mountains. Bouguer was the first who was struck with the idea of finding in mountains a proof of the universal attraction of matter. His investigations in the slopes of Chimborazo, combined with astronomical measurements, showed a deviation of the plummet of seven to eight seconds. Maskelyne found the deviation at the foot of Shehallien in

Scotland (1772), to amount to 54 seconds, and obtained from this the mean density of the earth at 4.45.

f. Of Impact.

In most cases the forces by which a body is moved, act only on a small part of the molecules of which it is composed, and yet all parts of the body move, those struck as well as those not touched. Thus, for example, a billiard ball rolls along, although, strictly speaking, only a small part is struck by the player. The motion must therefore be uniformly distributed to all the molecules; this takes place, however, in an infinitely short time, and the force has then passed on into the body, and distributed itself in it uniformly. The body thus impelled will continue incessantly to move in the direction of the impulse with uniform velocity, unless hindered by friction or the resistance of the atmosphere. The action of the force is therefore momentary; its effect, however, unlimited.

Under such circumstances the body receives the force, and one and the same force acting upon different bodies must produce very different motions; a force which can impel a small body with tolerable swiftness may hardly move a larger. It is usually said that this difference depends upon the weight, but this is not the case; else, if the body ceased to be heavy, the same force would impel all bodies with equal velocity. This, however, does not follow, as even in vacuo the same force must produce a less velocity, as the matter to be moved is greater; and the theory of mechanics teaches us that the same force operating upon different bodies, communicates to them velocities which are inversely as their masses, that is, as the quantity of their matter. Consequently, the same force that would impel a mass with a velocity = 1, would impel one of ten times the greater mass with one tenth of the velocity. Multiplying each of these masses by their velocity, the products will be equal; this product is called the *quantity of motion*, or the *momentum*. Machines cannot increase the quantity of motion, as they do not generate force, but only change the kind of motion. Thus a laborer can, by means of a rope which passes over a fixed pulley, easily raise 25 pounds to a height of $2\frac{1}{2}$ feet in a second; if, however, the rope were laid over a wheel and axle, where the latter should have a four times smaller diameter, the laborer, with the same exertion of strength as before, would easily raise four times the weight, but would require four fold the time.

If a body in motion meet one that is stationary but movable, it imparts to this latter a part of its motion, without thereby changing the quantity of motion; for if the striking body did not rebound in consequence of its elasticity, and if the blow were a central one, both bodies after the blow would move in the same direction, but always in mutual relation to their masses. The velocity after impact can therefore very readily be obtained by dividing the velocity of the moving body by the sum of the masses of the moving and the stationary body. Suppose a ball moving with a velocity of 1400 feet in a

second, and weighing half an ounce, to strike a ball of 40 lbs. weight suspended to a string, then the common velocity after impact would be to 1400 as $\frac{1}{32} : 40 + \frac{1}{32}$; thus $= \frac{1400}{1281} = 1.09$ feet in a second.

Upon this principle depends the measurement of great velocities by means of the *ballistic* pendulum. This pendulum, represented laterally (*pl.* 17, *fig.* 37), and in front (*fig.* 38), consists of an iron-bound wooden block, B, of considerable weight, which, by means of the iron frame, *r*, *m*, *s*, is attached to the axis, C, in such a manner that it can swing about this axis, which is supported at D. Above is attached a graduated arc, *no*, on which an index shows the amplitude of oscillation; beneath is an arched piece containing a groove filled with soft wax, on which the index, *f*, in the motion of the pendulum, makes a scratch, exhibiting graphically the length of oscillations whenever a ball, A, strikes the pendulum in the direction of the centre of gravity. The pendulum is 10—12 feet in length. To determine the velocity of a cannon ball it is fired against the pendulum, and its motion is thus communicated to the latter. Knowing the arc described by the pendulum, as well as the mass of both pendulum and ball, it is a simple problem to ascertain the velocity of the ball.

C. Statics of Fluids.—Hydrostatics.

a. Pressure of Liquids.

As the statics of solid bodies had reference to the laws of their equilibrium, hydrostatics embraces the theory of equilibrium in liquids, and of the pressure which they exert upon the walls of the containing vessel.

In liquid bodies, two forces are to be considered, namely, weight and molecular attraction; and these two forces may be readily imagined to be separated from each other, that is, a liquid may be supposed to exist without weight. Such a liquid left to itself would not fall: it thus needs no support on any side, and might even sustain a pressure and transmit it according to a certain principle. Hence the following axiom: a liquid transmits pressure acting upon any part of its surface, uniformly in every direction. Suppose a vessel to contain such a liquid, with a suitable piston, also without weight, placed upon its surface. The liquid would not flow out, even if the side of the vessel were pierced by an aperture. If, however, a weight be placed upon the piston, it would sink if not supported by the liquid, whose upper layer would likewise sink unless supported by the one beneath it, and so on to the bottom of the vessel. All these layers of liquid, therefore, receiving successively the same pressure, the result is the same as if the piston with its superincumbent weight pressed directly upon the bottom of the vessel. Hence it follows, that the pressure upon horizontal surfaces is transmitted from above to below without any loss, that is, is equal at every point, and proportional to the surface involved.

The same proposition holds good in reference to the walls of the vessel; for, supposing an aperture made in the side of the vessel by cutting out a piece equal in surface to the piston, the same weight as is placed upon the piston would be required upon this piece to prevent the liquid from escaping, and the resistance would be in proportion to the surface of the piece cut off. If the piston itself were pierced, the liquid would escape through it; liquids, therefore, transmit pressure uniformly in all directions. The laws thus developed for weightless liquids apply equally to those with weight, as it is here the single molecules which receive and transmit the pressure.

Another proposition with regard to liquids is the following: when a liquid is in equilibrium, its surface must be perpendicular to the direction of gravitation. When liquids are in equilibrium, they exert upon each other and all solid bodies with which they are in contact, a greater or less pressure: this pressure upon the bottom of a containing vessel being, without any regard to its shape, equal to the weight of a vertical column of the same liquid, which has the bottom of the vessel for its base, and the perpendicular height of the water for its altitude. Haldat's apparatus (*pl.* 18, *fig.* 1) serves as an illustration of this law. It consists of a bent tube fastened in a box and so adjusted as to admit of attachments of various forms (*figs.* 2—4) being screwed on at one end instead of *dh*. Mercury is now poured into the tube, and the height, *n*, noted to which it rises in the arm *c*. The cylindrical vessel, *d*, is screwed on to the left hand and filled to a given height, *h*, with water, and the increased height, *p*, of the mercury observed in the other arm. The rise of the mercury is evidently the result of pressure exerted upon it by the water in *d*. Let off the water by means of the cock, *r*, and exchange the vessel, *d*, successively for *figs.* 2—4, filling them with water to the same height, the mercury will each time rise to the same height, *p*, although the amount of water in the different cases is very unequal.

The pressure experienced by any portion of the side of a vessel is represented by the weight of a column of liquid, whose horizontal base is equal to the area of the portion in question, and whose altitude is the depth of its centre of gravity below the surface of the liquid. *Fig.* 5 illustrates the pressure upon the different points of the vertical side of a vessel. Erect at any point, *a*, a perpendicular to *rs*, and make this equal to *ar*, or the depth of the liquid at this point below the surface, then *ab* represents the pressure experienced by the point, *a*; suppose similar perpendiculars erected all along *rs*, then the entire isosceles right-angled triangle thus produced, will represent the entire pressure exerted upon the side in question. If *o* be the centre of gravity of the triangle, then a line drawn horizontally from *o* will intersect the wall in a point, *c*, called the centre of pressure: its height above the bottom is one-third of the height of the surface of the liquid.

In vessels communicating with one another in any manner, *figs.* 6 and 7, for instance, the surfaces will stand at the same height, if the same liquid be contained in both vessels. Suppose in *fig.* 6 a horizontal partition to be passed through *m*, then, if F represent the area of this partition, and *h* the height *vv*, the pressure on the partition wall from below will be = F*h*. In the broader vessel, if the height, *am*, at which the water is supposed to stand

be represented by h', the pressure upon F will be represented by Fh'. Suppose the partition wall now replaced by a layer of water, this will experience a pressure from above of Fh', and a pressure from below of Fh; equilibrium can therefore only exist when $h = h'$, or when the level is equally high in both vessels. If the liquid in the different vessels be different, however, the level will be unequal. If, for example, in *fig.* 8, one vessel contain water and the other mercury, they will meet each other in the plane passing through *g*. Below the plane *gh* there is only mercury; above it in the one vessel there is water, in the other mercury, the water pressing upon the mercury so as to force it into the smaller vessel in proportion to its height, never, however, attaining to the same level. The heights of the liquids will naturally be inversely as their specific gravities, and as these are as 1 : 14, the column of water must be 14 times the height of that of mercury.

b. Law of Archimedes; Specific Gravity.

Under certain circumstances, heavy bodies may move in a direction opposite to that of gravity. Thus wax and wood rise from the bottom to the top of a vessel filled with water; a piece of brass rises in mercury, &c. All these phenomena depend upon that important law first discovered by Archimedes, and named after him. A body immersed in a fluid loses in weight by an amount equal to the weight of the fluid displaced. This may be explained by means of *fig.* 9, *pl.* 18, where a combination of several vertical prisms is immersed in a fluid. The proposition is readily proved for a single right prism; as in this case the pressures on the different sides of the prism mutually balance each other, it is only necessary to consider that upon the top and bottom. The upper surface experiences a downward pressure equal to that of a column of fluid whose base is this upper surface, and whose altitude is the height of the fluid above the surface of the prism. The lower surface, on the other hand, is pressed upwards by a force equal to the column of fluid whose base is the lower base of the prism, and whose height is that of the fluid above this base, equal, therefore, to the height of the fluid above the prism, plus the height of the prism itself. The heights of these two columns differ, therefore, by the height of the prism, and it is therefore evident that the pressure from below, or the upward pressure, exceeds the pressure from above or the downward pressure, by the weight of a column of fluid equal in volume to the prism immersed. This excess of upward pressure acting contrary to the weight of the body, or to its gravitation, necessarily relieves the latter of an amount of weight equal to that of the fluid displaced. All bodies, of whatever irregularity of shape, may be considered as composed of right prisms, to each of which, and consequently to whose sum, the above reasoning will apply. A convincing proof of the accuracy of this law, which applies to both liquids and gases, may be had by means of the apparatus figured in *fig.* 10. At one end of a common balance is suspended a hollow cube of metal, beneath

which is attached a solid cube, fitting exactly in the first one. Place the one in the other, and bring the balance to a state of equilibrium by loading the opposite scale with weights; suspend the solid cube beneath the hollow one, and allow the former to be immersed in the water, equilibrium will be disturbed, and the weight scale will sink; fill the hollow cube with water, and equilibrium will again be restored.

A perfectly homogeneous body floats in a fluid when its weight is equal to that of the fluid displaced, and it may then assume any position; if, however, its centre of gravity do not coincide with that of the fluid displaced, it only floats when the two centres lie in one and the same vertical line; the position, however, is fixed, only when the centre of gravity of the body is the lower of the two. Thus fishes float in water when they weigh as much as the water displaced; the equilibrium of their position, or the inferior situation of their belly, depends upon the air-bladder, and is so placed that the upper part of the fish is lighter than the lower. By means of the air-bladder, the fish can rise or sink in the water, floating at pleasure at any height, by its simple compression or expansion. As the fish cannot inspire air at pleasure, like an air-breathing animal, the bladder must contain a certain quantity of gas (consisting in most fishes of $\frac{9}{10}$ oxygen and $\frac{1}{10}$ nitrogen), which is compressed more by the muscles than by the surrounding fluid. This muscular compression is, of course, voluntary on the part of the fish, and the compression or expansion of the bladder stands in intimate connexion with it. The apparatus (*pl.* 18, *fig.* 11) known as the *Cartesian Devils*, illustrates this condition of things. The devil is a hollow glass figure, *b*, in which there is a very small opening, generally in the point of the tail. The figure is filled with water just enough to make it float in a vessel filled with water. Cover the vessel with a bladder, and place it inverted upon the stand, in which is placed a strong spring, *e*; then by the pressure of the spring, the air in the vessel is compressed, and the water driven into the inside of the figure, compressing the air already contained therein. The weight thus increased, the figure necessarily sinks to the bottom. Relax the pressure of the spring, and the air in the figure expanding again, forces out part of the water, thus allowing it to rise. Here the figure represents the bladder of the fish, and the pressure of the spring the muscular contractions exerted upon that organ. The gas in the bladders of fish, taken at a depth of about 3000 feet below the surface, sustains a pressure of almost 100 atmospheres. The expansion, when the fish rises to the top, is so great as sometimes to force the viscera out at the mouth.

The determination of the *specific gravity* of bodies is a very important application of the law of Archimedes. Various forms of apparatus have been devised for this purpose; a few only can here be mentioned.

The *hydrostatic balance* (*pl.* 18, *fig.* 12) used for this purpose, is a very accurate balance, such as is employed in chemical manipulation, and as will be described more fully under the head of chemistry. Any chemical balance may be employed for this purpose, by removing one scale-pan and substituting another, which, although of the same weight, is hung much

shorter, and provided with a little hook beneath, from which the body whose specific gravity is to be ascertained, may be suspended. The absolute weight of the body thus suspended, is first to be ascertained by weighing it in the air, the weight being placed in the opposite scale. Place a vessel, D, filled with distilled water under C, and allow the body to be completely immersed in it, taking care to remove all air bubbles from its surface, its weight will of course be diminished, and to restore equilibrium, weights must be placed in C, or removed from D. The amount of these weights indicates the loss experienced by the body in its immersion, and consequently the weight of a mass of water equal in volume to that of the body itself. The specific gravity of the body is the quotient arising from dividing the absolute weight by the weight of an equal volume of water, or the loss of weight experienced when immersed in the water.

A very well adapted and useful hydrostatic balance is represented in *pl.* 18, *fig.* 13, giving a front view, and *fig.* 14, one from the side. To the main pillar, A, an arm is attached above, containing two pulleys, over which strings pass supporting a small beam to which the balance is suspended. The strings are united together into one behind the pulleys, and by means of the screw arrangement, C, may be drawn up or let down, the whole play amounting to 1—2 inches. The shears of the balance beam are pierced above, for the purpose of showing the point of the tongue, and thus determining whether equilibrium be attained or not. To the balance beam, B, are suspended the two scale-pans with small hooks beneath. DD′ is a thin plate attached to a special support beneath the scale-pans, admitting of being raised or depressed at pleasure. This plate, DD′, is pierced to allow passage to the brass wires attached to the hooks beneath the scale-pans. To the wire at D is attached a thin brass cylinder, pierced below, to allow anything to be suspended from it. This cylinder, about five inches long, is covered with paper, upon which an equally divided scale is drawn. In one corner of the plate, DD′, a wire passes with considerable friction through an aperture; to its lower end the index, F, is attached, which, by the friction of the wire in the hole, can be placed at any desired position with reference to the scale. At the lower end of the scale cylinder is attached a weight, G, and to this, by means of a fine wire, the brass ball, P, of about $\frac{1}{4}$-inch in diameter. To D′ is suspended, by a horse-hair, the large hollow glass bulb, P′.

Suppose the weight, G, to be removed, and the wire with P attached directly to the cylinder; suppose P′ also to be replaced with a weight, z, heavy enough to produce an equilibrium with the other scale and its appendages, when the middle of the wire, with P attached, is intersected by the surface of the water. The wire to which P is attached must weigh exactly four grains to the inch. As brass is about eight times as heavy as water, the wire will lose half a grain for every inch immersed in the water. If, then, everything be in equilibrium when the centre of this wire lies on the surface of the water, and if the index, F, lie against the middle of the scale cylinder, divided into 100 equal parts, the weight of a body can be ascertained accurately to within $\frac{1}{100}$th of a grain. Thus, lay the body to be

weighed upon the scale at D, and restore equilibrium, so that the difference shall be less than one grain. If the entire balance be raised or depressed, by means of the apparatus, C, until equilibrium is perfect, and if the index, F, point exactly to the middle of the scale cylinder, then the weights laid in D′ exactly represent that of the body in question. If, however, the index, F, point above or below the middle of the scale, as, for instance, to 36, then $\frac{36}{100}$ths of a grain are to be added to or subtracted from the weight already ascertained, as the case may be, to determine the absolute weight of the body in D. To determine the specific gravity, again attach the bulb or cup, P′, restore equilibrium, and then place the body to be examined in P′. The equilibrium again restored by weights placed in D′, and the indications of the index, F, will give the weight of the water displaced.

The specific gravity of solids may also be determined by means of Nicholson's areometer (*pl.* 18, *fig.* 15), which, by an error of the engraver, is represented inverted, and consequently requires an inversion of the plate to bring it right again. A small heavy mass, as a glass ball, filled with mercury, is suspended to a hollow glass body, V, whose upper part on immersion must project above the surface of the liquid. To the upper part is attached a fine rod, *f*, which carries a small pan, *c*. Lay upon this the body to be examined, and cause it, by means of additional weights, if necessary, to sink to a point, *f*. Remove the body from the pan, and substitute as many weights as will bring the point *p* of the areometer back again to the surface of the water: these additional weights give the absolute weight of the body, equal, we will suppose, to *n*. Remove the weights, *n* (not, however, those previously imposed), and place the body in a little basket between V and I. The instrument will not sink to *f*, this requiring the addition of weights in the upper pan. The amount of these latter weights = *m*, will give the weight of the liquid displaced, and the specific gravity = $\frac{n}{m}$.

To determine the specific gravity of fluids, a *scale areometer* (*pl.* 18, *fig.* 16), may be employed. This consists of a cylindrical glass tube, in the lower part of which a ball, *b*, is blown, which is continued into a smaller tube, terminating finally in another ball, *c*. This latter ball is filled with shot or mercury sufficiently to cause the instrument to sink vertically in distilled water to a certain point, the zero. In any other liquid the instrument will sink until its weight is equal to that of the liquid displaced; deeper, therefore, as the liquid is lighter: so that the specific gravity of the liquid can be ascertained by the depth of depression. For this purpose, the areometer of Gay Lussac has the point, *a*, at which it stands in water, indicated by 100, and upon the tube above and below this point, a divided scale attached, so that the volume of the tube included between any two divisions of the scale is $\frac{1}{100}$th of the volume sinking in the water, the numeration being carried from below upwards. An areometer divided in this manner is called a *volumeter*. The specific gravity of a liquid is ascertained by introducing the instrument and dividing 100 by the number on the scale to which it sinks. A volumeter of this character is the more sensitive as the distance

between the divisions is greater in proportion to the thickness of the tube: to avoid making them of inconvenient length, they are not made to be of universal application, but for particular liquids, or for liquids that are lighter or heavier than water. The zero of volumeters intended for liquids lighter than water is placed at the lower end of the scale, that for those heavier than water at the upper part; and the filling of the ball, *c*, is to be adjusted so that the tube *a* may sink to the proper point. The scale, which for every good instrument must be made especially, is generally on a slip of paper placed inside of the tube, which is then hermetically sealed above it. There are other areometers, which, more conveniently, give the specific gravity directly: in these the scale is not equally graduated, but the divisions increase from below upwards. For practical purposes, such areometers are much used for particular liquids, as alcohol, solutions of salt, milk, &c., giving the proportions in which they are mixed with other substances. They receive particular names, according to the fluid for which they are destined: Alcoholmeter, Saccharometer, Lactometer, Hydrometer, Salometer, &c.

c. Attraction between Solids and Liquids.

If the extremity of a fine tube be immersed in a liquid, the level of the latter will be higher or lower inside the tube than outside of it, according as the tube is moistened by the liquid or not; thus, in a glass tube immersed in water, it will be higher (*pl.* 18, *fig.* 17), and immersed in mercury it will be lower (*fig.* 18). The force which causes these phenomena of elevation or depression is called *capillarity*, or *capillary attraction*, and comes into play whenever solids and fluids are brought into contact. In such cases, the heights of elevation or depression of the liquid are inversely as the diameters of the tubes; the finer these are, therefore, the higher is the rise or fall of the liquid. For the empirical determination of this law, a very accurate direct measurement of the place of the liquid in the tube becomes necessary; and for this, the apparatus invented by Gay Lussac answers very well. In this, apparatus (*fig.* 19), the height of the liquid in the tube can be ascertained by means of a small telescope, *g*, moved up and down a graduated post, and capable of being fixed at any elevation. Having fixed the post of the telescope in a vertical position by means of the adjusting screws and the plummet *f*, the height of the liquid in the tube is to be noted, the tube then moved aside, and the plate *h*, through which passes with some friction a finely-pointed rod, *k*, laid upon the vessel *a*. The point of this rod is to be brought in exact contact with the surface of the liquid, and the height read off by means of the telescope. The difference of these heights will be the height of the column of liquid in the interior of the tube.

It must not be forgotten that whenever a liquid rises or falls in a narrow tube, the summit of the column is not perfectly flat, but concave in the first case, as in *fig.* 20, and convex in the second (*fig.* 21), the radius of

convexity and concavity being equal to the inner diameter of the tube The regularity of this structure, however, depends entirely upon the cleanness of the inside of the tube.

If a capillary tube which has been employed in any of the above-mentioned experiments be raised out of the liquid, the liquid originally contained therein will be retained there by the pressure of the atmosphere, and a drop which may have been suspended to the lower end will even be driven inside; and with sufficiently thin walls, the height of the column of liquid may thereby be raised to nearly double the original amount. Syphon tubes exhibit similar phenomena; and in concentric tubes the phenomena of capillarity take place in the inner tube and the ring between the two, as if each one alone were present. If, therefore, the diameter of the tube be twice as great as the thickness of the tube, the summits of the columns will be equally high in both. Parallel plane plates may be considered as parts of infinitely great concentric tubes, and experiment has shown that the phenomena of capillarity are precisely the same in the two cases. If the plates are inclined at a very acute angle, as in *pl.* 18, *fig.* 22, ADBE and CDBF, the liquid in the narrow part will rise higher than in the wider, and in such proportion, that the areas of the rectangular transverse sections, as *ab* and *cd*, are always equivalent. The shape of the curve, DE, forming the outline of the fluid, is that of an equilateral hyperbola, whose asymptotes, on the one hand, represent the line of intersection of the plates, and on the other, the level of the liquid. If the plates be removed from a vertical position to a horizontal, and a drop of water be interposed, it assumes a circular form, and passes to the line of intersection of the plates, and this with a rapidity greater in proportion to the sine of the included angle. Similar phenomena are exhibited by conical tubes. The small column of liquid, *mm'*, moves towards the point of the tube, as in *fig.* 23, and towards the broad end, as in *fig.* 24, and in the two cases assumes either a convex or a concave outline.

As a general rule, solid bodies cannot come in contact with fluid without the surface of the latter experiencing a greater or less change. Particularly remarkable in this respect are the phenomena of attraction and repulsion presented by bodies swimming in liquid. Two balls swimming in liquid and moistened by it, as balls of cork in water, when within sufficient proximity, attract each other with considerable intensity (*fig.* 25); likewise, two balls not moistened, as of wax (*fig.* 26). On the other hand, two balls repel each other when one is moistened and the other not (*fig.* 27). Similar phenomena are presented by vertical plates (*figs.* 28 to 30).

Another of the phenomena of attraction is the adhesion of plates to the surface of water, so that when they lie horizontally upon this surface, they can only be raised by the exertion of a greater or less force. The amount of this force is dependent upon the density of the fluid, increasing with this density. The material of the plate produces no difference in the result.

We cannot here go into an elucidation of the theory of capillarity, but will only remark that, according to the most recent theory of Mile, capil-

larity is nothing else than a mechanical molecular activity, which produces the drop and the bubble—the negative drop—and which is modified by the influence of the narrow space and of the adhesion.

d. Endosmosis

It is well known that a concentrated aqueous solution of any substance may be diluted with perfect uniformity throughout; if, however, there be no immediate contact between the water and the solution, but the two be separated by a porous partition with very fine pores, the liquid must pass through these pores to become mixed together. It may very often happen, however, that this partition admits of a more ready passage to one liquid than to the other, and the levels of the two, in their respective compartments, will then be different. Filling, for instance, a glass cylinder closed at the bottom by a bladder, with a concentrated solution of blue vitriol (sulphate of copper), and placing this in a vessel of water, the water will pass through to mix with the solution; the elevation of the liquid in the inner cylinder consequently rises, that in the outer vessel falling. If the inner cylinder be the one filled with water, the reverse will be the case, a depression here ensuing instead of an elevation. These phenomena investigated by Dutrochet, and by him named *endosmosis* and *exosmosis*, are exhibited sensibly in the apparatus figured in *pl.* 18, *fig.* 31, and by its inventor, Dutrochet, called *endosmometer*. The glass vessel, *b* is closed inferiorly by a piece of membrane or bladder, *cd*, and filled to a certain height with alcohol, the upper end stopped by a cork in which a glass tube, *a*, is fixed air-tight. This apparatus is placed in a larger vessel filled with water, and likewise closed by a cork, through which passes the tube, *a*. If the surface of water in the latter stand, say at *n*, equilibrium soon takes place, the surface of the alcohol standing perhaps at *n'*. Endosmosis now commences, the water penetrates the bladder against the resistance of the alcohol, and the alcohol column rises above *n'*, finally running out of the open end of the tube. If the experiment be reversed, so that the water shall occupy the place of the alcohol in the smaller vessel, the level will fall in the latter, owing to an ensuing exosmosis. Both operations continue until the liquids on each side of the membrane are homogeneous, and the difference of level is simply the result of the pores of the membrane being too minute to permit the action of hydrostatic pressure: for, if this membrane be moistened even on the side opposite to the liquid, no drops are found. Endosmosis and exosmosis play a great part in the organic world, since absorption and the distribution of the nutritious juices are almost entirely results of these operations.

D. Dynamics of Liquids; Hydrodynamics; Hydraulics.

a. Velocity of Efflux.

Hydrodynamics exhibits the laws of motion of liquid bodies; and at the head of this part of natural philosophy stands the law of Torricelli, that when an aperture is made in the side or bottom of a vessel filled with liquid, this liquid escapes with a velocity equal to that which would be attained by a body falling freely from the surface of the liquid to the orifice of discharge. According to this, the velocity of efflux is entirely independent of the nature and specific gravity of the liquid; it is in connexion, however, with the depth of the orifice below the surface, and is as the square root of the height of pressure. A convenient form of apparatus for experiments upon the efflux of liquids is represented in *pl.* 17, *figs.* 32, 33. The main part consists of a cylindrical tin vessel, communicating with a glass tube, in which the liquid stands at the same height as in the vessel itself; this height is measured by a scale attached to the tube. In the side of the vessel are two apertures, *b* and *c*, one above the other; there is a third opening in the bottom of the vessel, on which account the small table supporting it must have a hole pierced through it; a fourth orifice is to be found at *a*, in a short horizontal tube. This latter part is represented on a larger scale in *fig.* 33. Through the wall of the vessel, *aa*, passes a tube, *d*, which ends in a shoulder. In this tube is a second smaller one, capable of rotation about its axis, within the first. In the side of this smaller tube is a thin plate of brass, with the efflux aperture screwed in it, and by turning the tube this aperture may be directed vertically up or down, sideways or obliquely. By means of the valve, *c*, the access of water to the aperture, *b*, can be regulated at pleasure, the other apertures having also valves raised by strings when the water is to flow out through them.

To prove the Torricellian law by experiment, suppose the water to pour out of the point *a*, in *fig.* 32, with the same velocity as if it had fallen from the surface of the water to the depth *a*, then the stream of water must again attain the same height. This, however, is by no means the case, as the water falling from the highest point of the column retards the ascent of that following after it, as is shown by the fact that the stream ascends considerably higher when its direction is so inclined as to prevent this interference. Under favorable circumstances an altitude can be obtained equal to nine tenths of the depth of fall; the remaining tenth is accounted for by the resistance of the atmosphere and the friction of the sides of the tube. Allow the water to pass out from *b* or *c* (*fig.* 32), and the stream will be as represented in *fig.* 31: it will form a parabola whose shape depends upon the velocity of efflux. The theoretical parabola will, however, differ from the actual, in the ordinate being less than that of calculation, the reason lying in the retardations of atmospheric pressure and of friction.

The stream of water, immediately after leaving the orifice, contracts to two thirds of its diameter, this contraction continuing, although in an insensible

degree. In streams directed upwards, the jet expands continually after it has reached its greatest contraction of two thirds of its diameter, at a distance from the orifice equal to its diameter. The stream retains its constant form during only a certain part of its length; then it is separated into greater or smaller currents, which assume very various forms according to the shape of the orifice of efflux.

Should the efflux take place not through a thin plate but through a tube, considerable changes take place if the tube have not the shape of the compressed stream of water. Cylindrical escape pipes do not produce any difference under great pressure; at a less pressure, however, they increase the discharge, this taking place to a still greater extent in conical pipes: in all these cases, however, the velocity of efflux is diminished.

b. Lateral Pressure.

Pl. 17, *fig.* 30, illustrates the laws of the lateral pressure of moving liquids. If water flow from a vessel, A, through tubes, their sides will experience no pressure if there is no friction to overcome, but by this a considerable part of the hydrostatic pressure is lost, and acts upon the walls of the tube. The narrower the tube, the greater is the friction, and so much less the velocity of efflux. The pressure which the walls of a tube, *cf*, have to experience, will be less the nearer to the aperture of efflux, *f;* making then an aperture at *c*, and erecting in it a vertical tube, the water will ascend to a height, *cb*, corresponding to the pressure on the walls of the tube at this point. Midway between *c* and *f*, at *e*, the pressure on the walls is only half as great; the water would therefore rise only half as high as at *c*, namely, to *d;* and placing in any other part, between *c* and *f*, a vertical tube, the level of the water would lie in the straight line, *bf*.

To measure the pressure of falling water, the apparatus represented in *pl.* 18, *fig.* 72, may be employed. Upon the foot, B, stands a cylinder in which the post A may be fixed at different heights. DF is a balance beam, whose horizontal position may be determined by the index on the graduated arc C. At E hangs a common scale-pan, and at F is a plate whose size equals that of the efflux orifice of the vessel G. Letting a stream of water fall upon F, it will press downwards upon this plate, and the horizontal position of the beam is to be restored by weights placed in E. These weights will represent the pressure of the water.

c. Reaction and Impact of Water.

If a vessel be filled with water, without an aperture in any part of it, everything will be in equilibrium; if, however, in any part of the vessel an opening be made and efflux allowed, the pressure ceases at this point, and is consequently less than on the part of the vessel diametrically opposite: the vessel, then, if allowed, would move in a direction diametrically opposite to

that of efflux. Upon this principle depends the efficacy of Segner's water wheel. This consists of a vessel capable of turning about a vertical axis, at whose foot is a horizontal tube, bent in opposite directions at the two extremities, and in the same horizontal plane. The water escaping through these extremities produces a rapid rotation by the reaction of pressure on the sides of the tube opposite the opening; provided, however, that the pressure be sufficient to overcome the friction.

If a stream of water be directed against a movable body, it will cause a change in its position; and the force with which this is done will be in proportion to the amount of pressure. If, during the unit of time, as one second, a stream of water, whose height is M, fall from a height, *h*, M*h* will be the momentum of this column of water; and the force obtained by the impact of the water may be easily calculated.

The most important application of the impact of water is to be found in water wheels used for the propulsion of machinery. The most usual water wheels are vertical, with a horizontal axis. They are divided, according to the point of application of the force, into *overshot*, in which the water falls into the buckets of the wheels, from above and beyond the highest point; *undershot*, in which the water strikes against the lower float boards; and *middleshot*, or a medium between the other two. In the ordinary water wheels a good deal of power is lost; Poncelet has therefore constructed wheels with curved floats, which are much more powerful. Most powerful of all, however, are the so-called *top-wheels*, or *turbines*, invented by Fourneyron. In these the wheel is horizontal and the floats vertical; the water is carried through peculiarly constructed conducting curves against the floats, and turns the wheel around like a top, with such force indeed that 75—80 per cent. of the force of water employed is effective. In the division of the work specially devoted to Technology and Machinery, reference will again be made to the technical application of water power; where also the construction of the water-column machine will be explained—a machine in which the pressure of the water acts upon the piston of a pump, producing a backward and forward motion, which can be transmitted by proper connexions to other machinery. We may mention, in conclusion, another hydraulic machine, which can be employed to great advantage in many cases: this is the *hydraulic ram*, invented by Montgolfier in 1797, and employed in raising water. In *pl.* 17, *fig.* 36, *mm* is a horizontal tube, in which the water flowing from a reservoir moves with a velocity dependent upon the height of pressure. At *k* is a valve closed by the velocity of the escaping water; by it the aperture at this place may be closed. The water now pressing through the tube *i* into the cast iron reservoir *d*, enters, after raising another valve, into a great cast iron receiver (the air-vessel), and in this manner reaches the ascent tube, *ca*. Into this it is driven with a much greater force than would be produced by the height of pressure alone, as by the closing of the first valve, which suddenly obstructs the motion of the water escaping there, a pressure is produced upon the sides of the tube. In the ascending tube, the water rises to the height allowed by the elasticity of the air in the air-vessel, and the pressure of the water already raised; then the

valve leading to the air-vessel again closes; the conical valve first mentioned falls by its own weight; the water commences again to escape through it, and the play of the valves, or the butting of the ram, begins afresh.

E. Statics of Aeriform Bodies, or Gases.—Aerostatics.

Gaseous or aeriform bodies, among which the atmospheric air occupies the most important place, in some respects form a great contrast to the true liquids. At an earlier period, atmospheric air was considered as a simple body —an element; at the present day, however, its component parts are well known, and its place among compound bodies ascertained. It shares with the other gases, as well as with solid and liquid bodies, the same general peculiarities, and is also subject to the influence of gravitation and of molecular forces.

Atmospheric air surrounds the globe on all sides, having a thickness of from 30 to 35 miles; it is the cause of a great number of phenomena, some of which will here be referred to, others belonging to the subject of meteorology.

That the air had weight was known to Aristotle; Galileo, however, and, after him, Torricelli, were the first to prove this by experiment. Exhausting the air from a hollow globe, suspending this to the end of a balance brought into equilibrium by means of weights, and afterwards allowing the air to enter the globe, it will be found that equilibrium is again destroyed, and must be restored by the imposition of more weights: their amount will express the weight of the air contained.

The molecular force acts in gaseous bodies very differently from what it does in the case of liquids and solids, endeavoring to separate the molecules one from another, this influence being called *elasticity* or *tension* of gases. Of the activity of this force we may be convinced by introducing a well-closed bladder under the receiver of an air-pump. When a vacuum is produced, the contained air expands the bladder as exhaustion proceeds. The expansive force of air is unlimited, as in a state of greatest expansion it still exerts a pressure upon the containing walls. For this reason gases can have no free surface like solids and liquids, as they would extend illimitably into space; there is, therefore, for them only one condition of equilibrium, namely, that the elasticity in one and the same layer is equal, For equilibrium, therefore, the lower layers must constantly remain the densest; for which reason the pressure of the atmosphere must be greater at the level of the sea than on the tops of mountains. It must not be understood, however, from what has already been said, that as the air can have no free surface, the assumption of a limit of the atmosphere to some miles is erroneous. This rests upon grounds hereafter to be stated.

The atmospheric pressure may be measured; and to its existence innumerable phenomena testify. Immerse the lower end of an open tube into water, the fluid will rise into it, according to the laws of hydrostatics, to an

equal height with that surrounding it; suck some of the air from the tube, and additional water will enter, because the equilibrium of atmospheric pressure is disturbed. The air within becomes rarer and lighter; the external atmosphere, therefore, pressing upon the external surface of the water, forces it up into the tube until the air therein contained is compressed sufficiently to exert the same pressure with the outer, or, in other words, until the weight of the water raised is equal to the excess of external pressure. Exhaust the air entirely from the inside of the tube, and the water must rise until the weight of the column raised is equal to the weight of a column of air having the same base, and a height equal to that of the atmosphere. It has been found that a column of about 33 feet is the maximum that can be raised in this manner. Torricelli from these facts established the following conclusion: for two different columns of fluids to be in equilibrium, they must be to each other inversely as their densities. Mercury is fourteen times heavier than water; if, now, the pressure of the atmosphere sustain a column of water 33 feet in height, it will sustain one of mercury $\frac{33}{14}$ feet, or about 29 inches. That this is actually the case is shown by a simple apparatus for measuring the pressure of the air, termed the Barometer, consisting essentially of a glass tube about 31 inches long, closed at one end and filled with mercury. After filling this tube, hold the finger on the open end, and inverting it in a basin of mercury, remove the finger. The height of the mercurial column remaining in the tube, which in places at a slight elevation above the sea amounts to a mean height of about 28.6 inches, serves as a measure of the pressure of the air, as this, acting on the external surface of the mercury in the basin, sustains that in the tube. Along the top of the mercurial column, a scale divided into inches and fractions of an inch is attached, sometimes on metal, sometimes on paper, and occasionally upon the tube itself. To ascertain the amount of atmospheric pressure upon any given surface, calculate the weight of a column of mercury whose base is that of the given surface, and whose height is that of the mercury in the barometer.

Many different constructions of the barometer have been made, principally reducible, however, to two kinds, *cistern* and *syphon* barometers. The common barometer (*pl.* 18, *fig.* 32) is one of the first kind. It consists of a long tube, B, curved beneath and dipping into the vessel or cistern, C, upon which the pressure of the external air can act, as it is open. The whole is fastened to a board, A, and a scale, D, with a movable index, E, attached, to mark the variations of pressure by the rise or fall of the mercury. This scale is generally divided into inches, and tenths or twelfths, and a vernier frequently attached to the index for measuring very slight variations. The small scale, F, serves to measure the mercury in the vessel or cistern. Attention must always be directed to the vertex of the convexity of the mercury, which is formed in the ascent. In filling the barometer, care must be taken that there are no bubbles of air in the mercury, or attached to the tube, these being driven out by boiling the mercury in the tube. If these are not expelled they will rise into the top of the tube, and exert atmospheric pressure upon the top of the mercurial column, thus

neutralizing in some measure the external pressure, and causing the mercury to stand at too low a point; this undue depression will be increased, also, whenever expansion of the included air is produced by an increase of temperature. The empty space above the mercurial column of every barometer is called the Torricellian vacuum. The simplest barometers have only a straight tube, dipping directly into a separate vessel of mercury.

Since the barometer has been applied to the measurement of heights, the older construction for this purpose has been changed, and the *syphon barometer* (*fig.* 33) employed. This also consists of the tube, *b*, bent into a syphon shape at *a*, and closed at both ends. The short limb has at *c* a capillary opening which admits the entrance of air, but not the exit of mercury, so that the tube may be inverted without the contents escaping. To prevent the entrance of air into the larger limb during this inversion, Bunten has invented the construction represented in *fig.* 35. Here the mercury on inversion enters the space, *d*, so that the point of the downward projecting tube is, during inversion, constantly closed air-tight by the superincumbent mercury. It will readily be understood that in the figure only the lower part of the barometer is represented. In the syphon barometer, the quicksilver surface exposed to the pressure of the atmosphere has no fixed position, and the zero of the scale must therefore be brought to the place of the inferior surface.

In the barometer of Gay Lussac (*fig.* 34), the long limb, *b*, is bent in such a manner, that its upper part and the short limb, *a*, lie in the same straight line; the stations of the two surfaces can therefore be read off on the same scale, and then the zero is in the centre, so that the reading is of how much one scale is above, and how much the other is below 0; the sum is then the proper height of the barometer. This double observation is necessary on account of the influence of temperature upon the mercury.

The barometer of Fortin (*figs.* 36–38) is a cistern barometer, and has the advantage over others, that the mercury in the cistern, *a*, has an invariable level. The bottom of the cistern is formed by a leather pouch, *h* (*fig.* 37), against which a screw, *k*, presses, by which the surface of the mercury may be elevated or depressed. If then *g* be screwed fast to *i*, the surface of the mercury in the cistern must correspond exactly with the zero of the scale, which is at the extremity of a fine point. When the image of this point in the surface of the mercury is made to coincide with the point itself, the adjustment is made. The barometer is surrounded by a metallic tube, in whose upper part there are two opposite slits for observing the top of the mercury. The scale is attached to the metal tube. To assist the eye in determining the exact height of the mercury, there is a slider on the metal tube, which has also two slits corresponding to those of the tube, only a little broader. The slider is so adjusted that the upper edges of its slits coincide exactly with the top of the mercurial column.

Experiments and calculations instituted for the purpose, assign to a station of the barometer of 28.6 inches, an atmospheric pressure of about 14.6

pounds upon the square inch, which, upon a surface equal to that of the human body, amounts to from 30,000 to 40,000 pounds. This at first appears incredible, as it seems impossible to resist so enormous a pressure; the matter becomes more intelligible, however, when it is considered that the pressure acts on all parts, both inside and out, at the same time, so that the pressure from one direction is exactly neutralized by that from the other. This weight then is only sensible when the equilibrium is disturbed, as in a violent wind, &c. The compression or crushing of the body is resisted by the penetration of the external air into all the cavities of the body by means of innumerable fine pores as well as of larger passages, so that both inside and out, air is present in the same state of tension. This atmospheric pressure is of the greatest importance to the animal organism, as will be made evident by a single example. It is known that the head of the thigh bone consists of a ball playing in a socket of the pelvis inclosed in a capsular ligament, and possessing motion in almost every direction. If the leg be unsupported, and even if all the muscles and tendons be severed, the head of the thigh bone does not fall out of its place. If, however, the capsular ligament be pierced, or communication be made in any other way with the external air, the thigh immediately descends out of its place. It is thus evident that the pressure of the air upon this air-tight joint must play a great part in keeping it in position. In this manner may be explained the peculiar sensation of weakness and relaxation experienced at great elevations on mountains; the diminished pressure of the air takes from the whole frame its compact and well knit character.

One of the most important propositions in the theory of equilibrium of gaseous bodies, is the law discovered by Mariotte, and called after him Mariotte's law: that the volume of a gas is inversely as the pressure to which it is subjected. Thus twice the pressure is required to reduce a gas to half the volume, &c. Arago and Dulong have shown the accuracy of this law up to a pressure of 27 atmospheres, or a pressure 27 times that of one atmosphere. For this purpose they employed the apparatus represented in *pl.* 18, *fig.* 39. In the middle of an old tower, a mast, *a*, of about 100 feet in height, was erected, to which a long glass tube, *t*, was attached, composed of 13 single tubes of six feet in length. At the foot of the mast was a cast iron vessel, *v*, filled with mercury, with a forcing pump, *p*, attached at *b*, and provided with a manometer tube, *mn*, closed above, graduated, and filled with dry air. When the mercury stood at an equal height in the tubes, *t* and *mn*, the air in the latter, of known volume, experienced the ordinary pressure or that of one atmosphere. Forcing water, however, by means of the forcing pump, into the upper part of the vessel, *v*, the air in the tube, *mn*, would become compressed, and the mercury rise in the tube, *t*. The scale on the first tube gave the volume of the included air; the difference of height of mercury in the two tubes gave the corresponding pressure. *Fig.* 40 represents the manner in which the single parts of the vertical glass tube were united by strong rings, *aa'*; *c* is an upward projecting rim, filled with melted cement, to render any escape of mercury impossible. *Fig.* 41 shows how the manometer tube, *mn*, was fastened to the plate, *c*, of the cast

iron vessel, by means of the shoulder, *h*. The apparatus, *qy* (*fig.* 39), served to move along the vernier of the manometer, which was inclosed in a glass tube.

It has been mentioned above that the barometer was applicable to the measurement of heights, as the atmosphere in its lower strata exercises a greater pressure than in the upper, and that consequently the height of the barometer would be greater in one case than in the other. These measurements would be very simple if the air were not elastic, or at least very slightly compressible; for then, by obtaining a point of departure or unity by direct measurement of one height, other altitudes could be readily calculated. This, however, is impossible, as the less the pressure upon a layer of air, the less is its density; or in other words, the greater the ascent, the greater the rarity of the air. Mariotte's law renders it possible, however, to attain to accurate results. Suppose the height of the barometer at a certain elevation to be 760 millimetres, and by ascending 11.5 millimetres, the height of the mercury to be only 759 millimetres $= 760\left(\frac{759}{760}\right)$. Taking 11.5 metres as unity—then as the density of the air is proportional to its pressure, the next layer will be less dense, and, indeed, only $\frac{759}{760}$ as dense as the one below it; the height of the barometer then is there only $760\left(\frac{759}{760} \times \frac{759}{760}\right) = 760\left(\frac{759}{760}\right)^2$, and so on, so that for $n \times 11.5$ metres, the height of the barometer is $760\left(\frac{759}{760}\right)^n$. If now B be the height of the barometer at *a*, and B′ that at a place, *b*, higher than *a* by unity, and the quotient, $\frac{B'}{B} = q$, then, according to the preceding considerations, the height of the barometer for a place, *b*, higher by *m* units, will be $= Bq^m$, and *m* can be obtained from this equation. Thus $q^m = \frac{b}{B}$, and $m = \sqrt[q]{\frac{b}{B}}$. Here, however, must be taken into account the temperature and the vapors present in the atmosphere; the consideration of the corrections necessary on this account would carry us too far beyond our limits.

For determining altitudes where the greatest possible accuracy is not required, the easily transportable *Differential Barometer* of Kopp (*pl.* 18, *fig.* 42), may be employed to advantage. It consists of a straight cylindrical glass tube, *k*, united by means of a narrow tube with a glass vessel, *i*, closed tight above, through whose upper cap a thinner tube, *cd*, passes. In the tube, *k*, is a leather piston, which may be moved up and down. The instrument is filled with mercury, so that when the piston, *f*, is raised, in consequence of the atmospheric pressure, almost all the mercury passes from *i* into *k*, and the air contained in the vessel, *i*, communicates with the external atmosphere. A scale is attached to the tube, *cd*. Depressing the piston, the mercury is again forced into *i*, and there confines, as it closes

the lower end of the tube, *cd*, a certain quantity of air of the same density as that external to it. Continuing this depression until the mercury touches a point attached, similar to that described in the barometer of Fortin, the inclosed air becomes condensed, in a proportion dependent upon the dimensions of the instrument and the position of this point. If, for instance, the air were condensed to three fourths its original volume, the height of the mercury according to Mariotte's law, would be one third of the actual height of the barometer, and for this proportion, as well as any other, the actual height of the barometer would be obtained by multiplication into a factor developed from the construction of the instrument. If now there be another point in the instrument, standing somewhat deeper or lower than the first, it can be brought in contact with the mercury by a change in the position of the piston, where then the factor would of course be different. Making observations in immediate succession, and at the same place, with the two points, the products of multiplication by the different factors must be equal; the two points therefore control each other. There must, of course, be attached to the tube, *cd*, as shown in the figure, two different scales for the two points.

Upon the law of Mariotte depends an apparatus termed volumeter (*fig.* 93), invented also by Kopp, for determining the volume of powders. The tubes, *k* and *i*, correspond to those of the same name in the differential barometer, being likewise filled with mercury; from *i* passes a bent tube to the wide glass cylinder, *n*, whose upper broader end is carefully ground off for the purpose of placing a plate of glass upon it, and rendering it air-tight by the addition of a little tallow. Closing the cylinder, *n*, and depressing the piston, *k*, until the mercury touches the lower end of the ascending tube, a certain quantity of air will be inclosed in *l* and *n*: pressing down the mercury to the point, *a*, the included air will be compressed, a corresponding column of mercury rising in the ascending tube. If, before laying on the glass plate, any body had been placed in the cylinder, *n*, then the mercury standing at *c*, less air would be included than before, and in forcing the mercury up to *a*, it would be more compressed, so that the ascending tube would contain a greater column of mercury than before. From the height of this column of mercury the volume of the body contained in the cylinder is to be calculated. The powder to be examined is introduced in a platinum vessel, of about the shape of *n*, and nearly the same size. The volume of air included when the empty vessel alone stands in *n*, suppose it to be 15.07 cubic centimetres; and also the volume between *c* and *b*, say 2.5 cubic centimetres, to which the air is compressed, must be known. Now introduce the body whose volume is to be determined into *n*, and depress the piston again from its highest position, where *c* is closed by the mercury; a quantity of air, *x*, is inclosed, and when the mercury comes in contact with the point *a*, the air is compressed to $x - 2.5$. Let the column of mercury last obtained = 90 lines, and the actual height of the barometer = 336 lines, then the compressed air now experiences a pressure of $336 + 90 = 426$ lines, and $426 : 336 :: x : x - 2.5$; x, therefore, $= 11.72$. As now, when *n* is empty, the volume included = 15.07 cubic centimetres,

the volume of the body examined will be = 15.07 — 11.72 = 3.35 cubic centimetres.

Next to the barometer comes the air-pump, invented by Otto von Guericke, one of the most important instruments for elucidating the properties of the air. It serves to produce by successive rarefaction as complete a vacuum as possible, although this can never become so perfect as the Torricellian vacuum. Imagine a cylinder in which a piston moves air-tight, and closed below, then on raising the piston a vacuum will be produced. If, now, the cylinder be united with another inclosed space by a tube, so that the air can pass from the latter into the former, then, on raising the piston, the air would make this transit, but on depressing the piston it would return again. Suppose, however, a cock to be placed in the tube, by means of which the return of the air can be prevented, while its egress is allowed; then by the alternating action of the piston and turning of the cock, the air in the vessel may be reduced to a minimum, even if a perfect vacuum may not be attainable on account of the infinite expansion of air. This is the simplest construction of the air-pump; it has, however, since its invention, received various modifications and improvements.

Pl. 18, *fig.* 44, represents a small hand air-pump, according to the construction of Gay Lussac. The main part consists of a hollow cylinder or tube of brass, in which an air-tight piston plays up and down. In the latter is a valve opening upwards; thus shut during the ascent of the piston, and open during its depression. At *b* is attached the receiver, the vessel in which the vacuum is to be made, consisting generally of a plate and glass bell. The screws *a* and *f* serve to screw the air-pump to a table or board; at *d* a cock is attached, as also at *s*. If, now, the latter cock be opened and the former closed, and the piston elevated, a part of the air in the receiver will pass out through the first horizontal and then vertical canal, *ab*, into the cylinder, and the air in the receiver will become rarefied. Depress the piston after closing the cock *s*, and the air under the piston passes out through it by means of the valve in the piston head. To let the air again into the receiver, the cock at *d* must be opened.

A sectional view of a larger air-pump is shown in *fig.* 45, *pl.* 18. Here *a* is the cylinder, in which works the air-tight piston, *b*, which contains a valve opening upwards, and is moved by the piston rod, *c*. The rod *ed* opens and closes the valve for the cylinder; at its lower end is a truncated cone, *e*, fitting in a conical opening. At *h* is seen the glass bell to be exhausted, whose edge must be ground perfectly plane, in order that it may fit air-tight upon the ground plane, *pp*. In the centre of this plate is a female screw, *v*, for screwing on any other form of receiver; and from this goes a canal to the conical opening at *e*. If, now, the piston resting on the bottom of the cylinder be elevated, the valve at *e* opens until the shoulder at *d* strikes against the upper plate of the cylinder, and the air in part rushes from the receiver into the cylinder: on depressing the piston, the valve at *e* is closed, and the air in the cylinder escapes through the valve in the piston. At *r* is the barometer gauge, or contracted barometer, inclosed in a long narrow bell, and in communication with the air in the receiver by

means of the canal *ev*. The mercury at first completely fills the one leg of the bent barometer tube, but after a considerable rarefaction, begins to sink, and the difference of height of the two mercurial surfaces gives the pressure of the air in the receiver. If, for example, this difference amount to one inch, at a barometrical height of 28 inches, the air in the receiver will be rarefied 28 times. *Fig.* 46 represents a double-acting cock, *y*, in the canal between the receiver and cylinder, that is, a cock bored through in two directions: the one aperture is straight, and during exhaustion unites the receiver and cylinder; the other is bent into a knee, and opens into a lateral opening, which, during exhaustion, is closed by a metal stopper, *b*. To admit air into the receiver after exhaustion, the stopper must be extracted and the cock turned in such a manner that the air can penetrate into the receiver through the side aperture.

Air-pumps are divided into *cock* and *valve pumps*, and moreover into *one* and *two-cylindered*. *Fig.* 47 represents an air-pump provided with two cylinders. Here the two piston rods are toothed, and a piston interposed in such a manner that by the motion of a handle they can be alternately elevated and depressed, the one ascending, the other descending at any given time. In this manner the exhaustion goes on uninterruptedly, and is completed in much shorter time.

In the common air-pumps, however well they may be constructed, there is always a space intervening between the piston and its point of greatest depression and the bottom of the cylinder, which can never be exhausted. The air in it obstructs the rarefaction of air in the receiver, and sooner or later puts a stop to it. To obviate this difficulty, Babinet has constructed a cock of peculiar form, represented in *figs.* 48—50. In *fig.* 48, *a* and *d* are the two cylinders of a double cylinder air-pump, and *r* the cock attached between the two cylinders, a little below their base. This cock has four openings (*figs.* 49 and 50). The first and second, *s* and *t*, pass completely through and are perpendicular to each other; the third, *v*, is parallel to *s*, going, however, only to the centre of the cock, and opens in *t*. The same is the case with the fourth opening, *u*, which runs parallel to the longitudinal axis of the cock. From the bottom of the two cylinders pass curved canals which terminate at *b* and *e* in the openings of the cock. At first, the cock is fixed in such a manner that the opening, *t*, unites both canals; and this position, in which it exerts no particular influence, is continued until the mercury will fall no longer in the gauge. The cock is now slightly turned, so that the bore, *s*, unites the two cylinders; and at the same time the opening *v* unites the cylinder *a* with the receiver. If the piston in *a* be depressed, the rarefied air beneath it is driven over into the other cylinder; when, however, the piston in *d* is depressed, the valve in the bottom of *d* is closed, and in the cylinder *a* the space above mentioned contains only rarefied air, so that the rarefaction in *a* is much greater than before. It is only after repeated strokes of the pistons that a new limit to rarefaction is attained.

The *condensing pump* (*fig.* 51) serves to condense the air, and differs from the air-pump merely in having the valves to open and shut in a dif-

ferent direction. In depression the piston drives the air into the receiver and compresses it; in elevation the external air opens the piston valve and presses into the tube, while the air in the receiver is retained by the valve in the bottom. The receiver must be screwed down, else it will be forced up by the compressed air. Many condensing pumps are so arranged as to be applicable to various apparatus or receivers in which the air is to be condensed. One of this kind is represented in *fig.* 52. It consists of a tube or cylinder, and a piston, *b*, without a valve. The receivers are screwed on to the lower end of the tube, either at *c* or *d*; a valve then attached admits only the ingress, not the egress of air. The receivers *f* and *i* may be closed when necessary by the cocks, *e*, *h*, and *g*. For admitting successive portions of air into the cylinder or tube, a lateral opening in the tube, or, as in the figure, a lateral valve, may be used. The latter serves principally when a gas, not atmospheric air, is to be condensed.

The air-pump, in its application, is confined not merely to physical experiment, but is of the highest importance in the arts. It is there employed on the one hand for rarefying the air, as in the steam engine and sugar manufacture, and on the other for condensing air, as in driving of machines by condensed air, in the air-gun, &c. In the air-gun the air-vessel in which the condensed air is contained is either a ball screwed on beneath the stock or it is the piston itself. This vessel has then a valve which prevents the escape of the included air, and upon which stands a pin connected with the discharge of the gun. Thus, when the trigger is pulled and the cock descends, this pin is pressed upon for an instant with such force as to open the valve sufficiently to allow the escape of enough air to propel the ball.

To measure the pressure of gas contained in a certain apparatus, pressure valves are partly used, and partly manometers, to which latter belong the barometer gauge of the air-pump, as also the *safety tube* represented in *pl.* 18, *fig.* 53. The latter contains a liquid, standing at an equal height in the two legs when the pressure is equal to that of the atmosphere. When this is not the case the liquid cannot stand at an equal height in the two legs; and from the difference of level, knowing the density of the fluid employed, the pressure in the interior of the inclosed space to which the tube is applied can easily be determined.

For pressure valves the relation is somewhat different, since while in manometers the internal pressure is measured by the height of the mercury or other fluid, in those it is given directly in terms of weight. The wall of the compressing vessel is provided with an aperture of determinate size, a square inch for instance, which is so constructed by opening outwards as to form the bed of a conical valve. This valve is loaded with weights, either directly or by means of a lever, upon which, as in the steelyard, a shifting weight may be placed. In such cases the valve when raised gives directly the pressure exercised by the gas, upon every square inch of surface. All these valves, however, give indications only when the

pressure is greater than that of the atmosphere; when it is less they are themselves kept closed by the pressure of the external air.

Upon the pressure of the atmosphere or compressed air depends the action of very many important and useful arrangements, apparatus, and machines, some of which will here be considered.

The pressure of the air amounts to about 14 pounds to the square inch; if then a vessel be constructed with an opening of not more than one square inch, and the pressure of the fluid therein contained does not exceed 14 pounds, then when filled it may be covered with a sheet of paper and inverted without the escape of the fluids on the withdrawal of the paper, this escape being prevented by the atmospheric pressure. Upon this principle depends the straight syphon, *fig.* 54. This is a tubular vessel, contracted above and still more below, and open at both ends. When dipped into a liquid so as to be completely filled, and the thumb placed upon the upper extremity, the tube may be elevated without the escape of the liquid, which only occurs on the withdrawal of the thumb. The *Syphon, fig.* 55, is a bent tube, *bsb'*, whose legs are of unequal length. If now the shorter limb be immersed in a liquid, and the entire tube filled by suction or other means, the liquid will continue to flow from the extremity of the long limb, until the opening at *b* is laid bare—provided, however, that the extremity of the long limb always occupies a position lower than that of the shorter one. For the purpose of more conveniently filling the syphon and obviating any danger of getting the fluid into the mouth, a sucking tube, as *at fig.* 56, is frequently attached. Closing the opening at *b'*, and sucking at *t*, the whole limb, *sb'*, will become filled; the escape of fluid will commence on removing the obstruction at *b'*, and continue until the fluid has run off to the level *bn*. This is sometimes called a *Poison Syphon.*

In this place belong the various forms of apparatus depending on the syphon, and called *Cup of Tantalus.* They are used principally for purposes of amusement, or to excite astonishment when a vessel filled with water empties itself spontaneously. *Fig.* 59[a] represents a metallic vessel divided by a floor somewhere near the middle into two parts. Through an opening of this floor passes a glass tube open at both ends, over which a larger tube is placed, *fig.* 59[b], hermetically closed above, and with only a small opening near the floor to admit the water. On pouring water into the vessel it passes through the small aperture into the large tube, standing in this as high as in the vessel itself. On rising as high as the top of the smaller tube the water runs over into the lower division, for which purpose the latter must have a vent-hole above to admit the escape of air. The water will then run off until its level reaches the aperture in the large tube, the lower part of the vessel thus becoming full as the upper is emptying. The experiment becomes most astonishing when the mechanism is concealed by some figure. *Figs.* 57 and 58 represent vessels which, properly filled, retain the water when standing erect, allowing it to flow out, however, when inclined. The vessel in *fig.* 57, as in *fig.* 59, is divided into two parts; through the bottom of the upper one there passes the long leg of a

syphon, the short leg resting upon this bottom. Pouring water into the vessel, so that its surface is a little below the inside of the curvature *b*, then in an erect position of the vessel the water cannot flow out; in an inclined position, however, as in drinking, this will immediately take place; the long arm of the syphon becoming filled and allowing the escape of the water. The same occurs in the drinking vessel, *fig.* 58, when inclined towards the left side.

In the first vessel the syphon lies concealed in its double wall, and the short leg has a small opening only at the floor, while the height to which the water is to be filled, and the point to which the water is to be applied, are accurately indicated. In the second vessel the construction of the double wall itself forms the syphon, and in this case the point to which the tongue in the double wall rises, and which must not be exceeded in filling, must be marked on the inside of the cup. In both cups the water runs into the lower division, whence it must be removed before the experiment can be repeated.

Finally, *pl.* 18, *fig.* 60, represents a very ingenious and amusing apparatus depending in principle upon the syphon. The principal part consists of a vessel divided into three compartments by a horizontal and vertical partition, one below and two above. Through the horizontal partition pass two tubes; a third passes through the covering of the upper division to the left, and at the same time through an open cup, into which a hollow bird, *i*, inclosing a concealed syphon, dips its bill. Filling now with water through the proper apertures, the upper apartments *f* and *c*, which, however, must not reach the upper opening of the tube at *e*, this water passes from the right hand compartment through the tube *d* into the lower chamber; the air displaced escapes through the tube at *e*, presses upon the water in the upper left chamber, and causes it to pass out in a jet through *h*, and to fall into the inclosing basin. As the air in the right chamber becomes rarefied by the depression of the water, the syphon at *g* is filled with water by atmospheric pressure upon the water in the basin; this then passes as if drunk by the bird, through the tube *g* down to *c* again.

Hero's Ball, fig. 61, consists of a strong well closed vessel, *v*, partially filled with water, in which at *j* a piece of thermometer or other fine tube, *t*, with a fine opening, passes through the stopper *a* nearly to the bottom of the vessel. If the air in the upper part of the vessel is compressed, as by blowing in air from the lungs, or if the air above the water is expanded by heat, the pressure of the air forces out the water in the form of a vertically ascending stream.

The *intermitting spring* (*fig.* 62) consists of a water vessel, *r*, with escape tubes, *j*, *j*, and a tube, *t*, whose upper end projects above the surface of the water at *r*, while the lower, which has a small notch in it, stands in a vessel, *p*. When the notch is free, the pressure of the atmosphere upon the surface of the liquid in *r*, causes this to flow out through the tubes *j*, *j*, into the vessel *p*. As soon as the lower end of the tube *t* is covered by the water pouring into *p*, the discharge through *j*, *j* ceases, because no more air can pass through *t* into the vessel *r*. In the meantime, however, the water

passes through a small opening in the bottom of the vessel *p* into the lower receptacle, the inferior opening of the tube *t* again becomes free, and the discharge through *j*, *j* begins afresh.

Hero's fountain is essentially nothing else than a self-acting Hero's ball, in which the compression of the air which drives out the water is produced by means of a column of water. *Fig.* 63 represents the apparatus in its simplest form, which, if not blown in one piece, may consist of vessels connected together by glass tubes. To use it, the upper vessel, *c*, is filled with water through *d*, until it stands nearly up to the termination of the tube *b*. Filling the vessel above *a* with water, the water descending in *a* compresses a column of air in *b*, whose elasticity and pressure upon the surface of the water in *c*, force out the water through *d*. *Fig.* 64 represents a somewhat more complicated form of this apparatus, where the tube *x* answers to the tube *a* in *fig.* 63, and *y* to the tube *b*; the vessel *z* occupies the place of the lower ball, and the upper vessel that of the ball at *c*; and at *a* is the discharge pipe, which reaches nearly to the bottom of the vessel.

A *pump* (*suction pump*) in its simplest form is a tube of uniform diameter within, open at both ends, and the lower dipping into water. In this tube may be moved up and down a well-fitting and air-tight piston attached to a rod. Supposing at first the piston to stand at or near the surface of the water, and that it be elevated by means of the rod, then the water, by the pressure of the air on the surrounding liquid, will be forced into the pump, and ascend to a height of not more than 32 feet. If the water is to be not only raised but turned into a receiver, its return must be prevented, and some provision made for getting it above the piston. The lower extremity of the pump tube in this case must not be open, but must have a bottom provided with a valve opening upwards; also with a suction tube dipping into the water where it may be closed by a strainer. The piston also must have a valve opening upwards. On raising the piston, the water is forced by atmospheric pressure through the lower valve into the pump tube, the valve in the piston remaining closed; on depressing the piston, its valve is opened by the pressure of the water, which then rushes through it and occupies a place above, the return of the water through the lower valve being prevented by its closing. By repeated elevations and depressions of the piston, the water is at length lifted to the level of the top of the tube, or to an orifice in the side where it can escape. If the water is not to flow directly from the pump tube, but into some other place, or if it is to be discharged with great force, or carried to a great height, the *forcing-pump* must be employed, as represented in *pl.* 17, *fig.* 34. It consists of a pump-stock or tube in which is a massive cylindrical piston, F, moving up and down, passing air-tight through a stuffing box, E, and a grease box, D, but without touching the pump tube itself, which therefore need not be perfectly cylindrical in its box.

Upon the suction tube, C, is placed the valve lid, *f*, with the valves *i*, *i*, through which, on raising the piston, the water passes into the cylinder; on depressing the piston, the water is driven into the tube B, after forcing open its valve, *d*. On raising the piston again, the valve *d* falls, and the valves *i*, *i*,

which had just been closed by the depression, are aga n open, and admit a fresh quantity of water, which also is then forced into B; the operation may thus be continued for any length of time. It is necessary to mention a special contrivance which must be attached to the pumps of this construction when the water is to be forced to a great height. The water, as is well known, contains a great deal of air mixed with it, which is set free during pumping, and collects under the piston. If, now, the column of water behind *d* has a great height, as of 40 or 50 feet, the air in A has to overcome a pressure of more than one atmosphere, and thus, instead of passing out through *d*, becomes compressed by the descending piston, expanding when this is elevated, so that when the amount of this air is considerable, it becomes impossible to produce a sufficient rarefaction in A to admit of the opening of the valves *i*, *i*, and the ingress of the water. Some plan must be resorted to, then, for removing the accumulation of air from the cylinder. For this purpose a canal, *abc*, is bored through the piston, to allow of an exit for the air beneath; a screw at *a* keeps this canal closed. If, now, a quantity of air has collected, as indicated by a diminished discharge of water, the screw *a* is to be opened on the descent of the piston, and closed when it has reached its lowest point, or when water escapes instead of air through the canal *abc*.

Suction and forcing-pumps find numerous applications in the arts and manufactures, and we shall have frequent occasion to refer to them in the technical part of this work. We will here only mention their application in hydrology, as, for instance, in the water-works at Marly, where water is raised to a height of over 500 feet. Here also belong the fire-engines, the largest of which consists of two forcing-pumps, working alternately, and driving the water into a larger air-tight vessel, whence it escapes through an escape-pipe. A more particular account of various kinds of fire-engines will be presented in the tenth division of the work.

The *hydraulic press* of Bramah, represented in full on *pl.* 18, *fig.* 65, and in section of the working part in *fig.* 66, is another application of the forcing-pump. It consists of two principal parts: a forcing-pump which exerts a pressure by means of the water raised, and a piston which receives the pressure and transmits it, through a plate resting in its upper extremity, to any body upon which pressure is to be exerted. The piston, *s*, is raised by the lever, *l*, and in consequence, the water presses from the reservoir, *b*, through the strainer, *r*, raises a valve, and thus gets underneath the piston. When this piston is depressed, the water closes that valve, opens the valve *d*, and passes through the canal, *tbu*, into the cylinder, *cc'*; here it presses against the piston, *p*, and raises it with the plate *p'*, so that any body between this plate and the fixed plate, *e*, experiences a great pressure. The force with which the smaller piston, *s*, is depressed, will be to the force with which the larger, *p*, is elevated, as the area of a section of the piston *s*, to the area of a section of the piston *p*. The amount of force transmitted to the piston *p*, is regulated and measured by a safety valve, *g* (*figs.* 67–69). Thus knowing the weight, *p*, the length of the lever arms, *fx* and *fy*, and the area of the lower surface of the valve, *g*, the pressure experienced by the valve

can be easily calculated when the lever, *fxy*, becomes elevated. The weight, *p*, must be so regulated as to admit of the raising of the valve only when the pressure has reached a certain limit. *Pl.* 18, *fig.* 70, represents the part through which the piston, *s*, passes, constructed so as to prevent the escape of any fluid. *Fig.* 71 is an ingenious contrivance of Bramah, intended to supply the place of a water-tight end of the piston, *p*. It consists of a bent leather, laid in an annular channel of the piston, and against whose walls, as well as against the piston, it is pressed the tighter with an increased pressure from below.

It has been before mentioned that the force increases with the ratio of the sectional surfaces of the pistons. When the smaller piston, *s*, is depressed, every part of the inclosing walls, equal in area to the bottom of the piston, experiences the same pressure as that with which the piston *s* is depressed. The lower surface of the piston *p* is, however, a part of these inclosing walls, and every part of the surface, equal in area to the bottom of the piston *s*, must experience the same pressure, and the sum of all these pressures will represent the force with which the piston *p* is elevated. Thus, if the small piston have an area of one square inch, and that of the larger 100 square inches, the force on *s* will be multiplied a hundred fold on *p*. By means of the lever, *l*, a pressure of 600 pounds can easily be exerted by one man on *s*, and the piston, *p*, must therefore be raised with a force of $600 \times 100 = 60{,}000$ pounds, and the same pressure exerted upon any body between *p'* and *e*. From this some deduction must be made for friction, &c.

A proof that the law of Archimedes, established for liquid bodies, applies also to gaseous, is furnished by the *Air Balloon* or *Aerostat*. Every body surrounded by, or immersed in the air, loses an amount of weight equal to that of the air displaced, and must therefore ascend in the atmosphere whenever its weight is less than that of an equal volume of air. Owing to the great lightness of the air, this can only be attained when a hollow body is filled with some very rare matter. These conditions may be fulfilled by making a bag of paper, gold-beaters' skin, or oiled silk, and filling it with rarefied air, or with a gas lighter than the atmosphere. Vacuum balloons, whose contents would be certainly of least possible weight, are not feasible, as independently of the great difficulty of exhausting air on so large a scale, they would be immediately compressed by the external air, unless made of some very strong material, as metal, in which, to compensate for the great weight, the size must be enormously large to produce an ascent.

Independently of the material, there are two principal kinds of air-balloons characterized by the mode of filling: 1, *Montgolfier*, open below and filled with heated, and consequently rarefied air. The source of heat must be at some distance below the lower opening, and must accompany the balloon in its ascent, to continue the rarefaction, which would otherwise be of short duration. This balloon derives its name from the inventors, the brothers Montgolfier, who caused the ascent of the first balloons at Annonay in France, June 5, 1783. The second kind of balloon is the *Charlière*, filled with hydrogen gas, which, when perfectly pure, is fourteen times lighter

than air. It derives its name from Professor Charles of Paris, who also, in 1783, employed this method of filling, and with one companion ventured on the first aerial voyage in a car attached to the balloon. Balloons of this latter construction are decidedly preferable, as being less exposed to the danger of catching fire than the other; and secondly, on account of the greater lightness of hydrogen, they may be made smaller, or when of equal size, they will sustain a much greater weight, and will ascend higher in the atmosphere. Hence, when an ascent is to be made by individuals, the Charlière balloon is almost always employed. The descent of this kind of balloon is effected by the escape of gas through a valve attached to the upper part, and regulated by a cord; and the higher ascent, by the discharge of sand bags taken along as ballast. The ascent of a balloon must of course cease as soon as it attains to a stratum of air of so slight density that the air displaced is no heavier than the balloon with its load.

Pl. 17, *fig.* 39, exhibits the construction of the valve for the escape of the gas used in the so-called *Hampton Balloon*. The balloon itself consists of forty-one strips of oiled silk, each of which is sixty-seven feet long and three feet broad; its circumference amounts to one hundred and twenty-three feet, its diameter to forty-one feet. The first constructed valves consisted of a simple door opened by a cord, in which case the aeronaut could not see how much gas escaped, and consequently sometimes let out more than he wished. The present valve consists of a hoop, A, four and a half feet in circumference, and six inches deep. At *dd* are spiral springs attached inside and inclosing the axis *cc*. The whole resembles the upper part of a drum. To the valve proper which turns about the axis *cc*, the draw cords, *bb*, are attached, of which the right opens the valve and the left closes it. The spiral springs *dd* would of themselves close the valve, the cord being attached merely by way of precaution. Over the straight part of the springs pass two rings which spring off when the valve is opened to a certain point. This latter then remains open and the gas entirely escapes. This takes place when the balloon is on the ground, otherwise the aperture may be regulated to $\frac{1}{8\,9}$ of an inch. The cords used in this balloon are of cocoa fibres, as being stronger and lighter than common.

An appendage very frequently attached to the balloon, for the sake of descending from a considerable height, is the *Parachute*, A, *fig.* 40. Its principle depends on the resistance of the atmosphere, which diminishes the velocity of descent of every falling body, and this the more, as the surface of the body is greater in proportion to its weight, and as the velocity already attained is greater. The parachute, at the ascent of the balloon, is placed between it and the car, C, to which latter it is fastened: on breaking the connexion between balloon and car, the latter immediately falls with increasing velocity, the parachute being at first folded up, but expanding more and more until at length it sweeps over the car in the form of a great umbrella from 25 to 30 feet in diameter. The velocity then decreases to a less dangerous amount, which it retains until the ground is

reached, which is done with impunity. The anchor D serves to attach it to the earth.

Pl. 18, *fig.* 73, represents an ordinary balloon, A, with its valve at C, and to which is suspended the car D by means of the network F and the cords E, E, E, E. B is the hose through which the balloon is filled. *Fig.* 74 represents the copper balloon constructed in Paris according to Marey Monge's plan for conducting physical experiments in the upper strata of the atmosphere. The segments are of copper plate, about one eighth of a line thick, and the joints well soldered. The balloon is thirty feet in diameter, weighs 800lbs., and contains about 100lbs. of hydrogen gas.

The guidance of the balloon in any given direction has up to the present time not been accomplished; a rise and fall can indeed be effected, but not a horizontal motion, this being dependent upon the currents of the wind. For practical purposes the balloon is therefore inapplicable, and except for scientific purposes, its employment by the French army in military reconnoissance was the only application ever made of it. Experiments to effect a guidance of the balloon, and a motion in a determinate direction, have indeed been frequently made, and it may perhaps be advisable to refer in brief terms to several contrivances proposed for this purpose. *Pl.* 17, *fig.* 41, represents the *Flying Machine* of Henson (air steamboat), which, however, is essentially nothing but a great parachute, and has by no means answered its intention. AA are two wings, each one hundred and fifty feet long and thirty feet broad, constructed of iron work, over which is stretched a silk or linen covering; this latter consists of three parts, which can be opened or shut by means of a rope. The wings are sustained by the iron posts, B, B, and cords stretched over them, and are immovably attached to the firm middle part. The motive power consists of the fan wheels, D, D, set in rapid motion by the steam-engine, G; to this latter is attached the car for passengers, &c. The change of direction, in a horizontal plane, is produced partly by a rudder, partly by the tail, E, which is composed of a fan-shaped frame covered with silk, and movable freely about F. The visionary nature of this arrangement, presented here only as a curiosity, is evident at the first glance; any practical value is entirely out of the question, for the reason that no balloon is employed in its construction, but the machine must begin its journey from a high tower or lofty mountain, which journey then can be nothing else than a long protracted fall without any possibility of ascent. The aerial ship proposed by the Englishman Partridge, some years ago, and by him called *Pneumodrome*, certainly promises better results. It is represented in various details on *Pl.* 17, *figs.* 42—48, *fig.* 42 being a half-side view, *fig.* 43 a half-longitudinal section, *fig.* 44 a vertical transverse section, and *fig* 45 an end view, with the balloon partly omitted. The principal parts of the balloon consist of: 1. the balloon, A, of air-tight india rubber cloth, a square yard of which weighs about one pound, spheroidal in shape, and whose length, breadth, and height are as 7 : 4 : 2. For the filling the inventor employs pure hydrogen gas. As, however, the inclosed gas expands greatly at a height where the pressure of the atmosphere is much

less than at the surface of the earth, care must be taken to fill the balloon to only three fourths of its greatest capacity; in order, however, to cause it to appear equally stretched at all times, a second balloon is placed within the first, and about one fourth of its cubic contents. This second balloon is filled with air by a tube communicating with the car, but can be emptied through valves during the expansion of the gas. The balloon is, moreover, provided with a warming apparatus, partly by heating the gas in the large balloon to about 60° R., to distend the balloon completely, and so bring to bear the entire force of ascension; and partly to increase and diminish this ascending force at pleasure. This heating apparatus consists of a system of tubes, C, attached internally to the bottom of the balloon, and connected by a conducting tube with the heating apparatus or the boiler of the steam engine hereafter to be mentioned, so as to admit of being filled with steam or air. 2. The spar and sail work. To the balloon is fastened a light spar work, consisting of iron, covered externally with tin plate, and strengthened by braces and tight ropes. This rests against the spindle or middle column standing in the middle of the car, and consists of an iron frame covered with some air-tight material. In it is a strong spiral spring, which serves the purpose of weakening the shock caused by striking on the ground. In the spar work is a horizontal main-mast with the horizontal mainsail, D, D, whose two halves may be brought into any inclined position, to produce a change of horizontal and vertical direction according to the rules of navigation. H, H, are vertical sails for using the wind in change of vertical direction. 3. The car with the steam-engine. The former is fastened in the spar work, and provided beneath with strong spring buffers to weaken the shock in the descent of the vessel. It is divided by a floor into two compartments, the lower intended to serve as a coal, water, and freight room, the upper one for the passengers and engine; the latter a high pressure and of the rotating construction. 4. The motive apparatus to be driven by the engine, consisting of three spiral wind wheels GG, and the horizontal wind wheels, FF (*figs.* 44, 46, 47), the latter attached above the car in the middle of the plane of the mainsail. They consist of wings turning in a box, in the centre of which the wind enters, to be again driven out at some point of the circumference. The object of these horizontal wind wheels is to produce an artificial current in a determinate direction, which, acting upon the part of the horizontal mainsail presented to it, produces an oblique upward or downward motion. As far as known, this idea of the Pneumodrome has never been carried out on a large scale.

F. Of the Motion of the Air.—Pneumatics.

If any aeriform body be confined in a vessel, it must escape through a given aperture whenever it becomes more condensed than the air in the space to which the opening leads. A vessel used for containing any kind of gas, and from which the gas will stream forth with a certain rapidity on the appli-

cation of pressure, is called a *gasometer*. Such vessels are constructed in various ways, according to the use to which they are to be applied. The principle of construction in all, however, consists of a vessel filled first with water, into which the gas is then admitted, displacing the water. By the direct application of a weight, or by means of a column of water which exerts a pressure upon the gas, this is forced out through tubes attached to the vessel. *Pl.* 19, *fig.* 1, represents a large apparatus of this kind, such as is used in gas works. It consists of a cylinder, B, of tin, closed above and open below, which sits in a great water reservoir of masonry. Two tubes, D and E, rise into the cylinder from below, their upper extremities standing above the surface of the water; the one tube comes from the apparatus in which the gas is prepared, and serves to fill the gasometer; the other, D, is closed by a cock during filling, and serves for the exit of the gas. At some distance from the gasometer it divides into several branches, which carry the gas to the various points where it may be required. The tube E has also a cock, which is open during filling, and closed when the cock in D is open. It is evident that only one can be open at a time. The pressure exerted by the tin cylinder upon the gas, and which may be increased by the superposition of weights, causes the escape of the gas, and may be regulated by the counterpoise, C.

To produce a regular stream of air, bellows and blowers are employed. A common *bellows* is the simplest means of producing a strong stream of atmospheric air. This consists of an air-tight leather or wooden box, whose inclosed space may be increased or diminished; air passing in through one small opening during the former, and passing out through a second aperture during the latter. A simple bellows of this kind cannot produce an uninterrupted stream of air, as it acts only intermittingly. To produce a continuous blast, a double or compound bellows must be employed, as represented in *fig.* 6. This consists of two sections, *a* and *b*. Press down the lower plate of the section *b*, and the air enters through a valve; press the plate up again, and the air compressed in *b* opens a valve between the two, and passes into the upper division, where it is compressed by superincumbent weights, and must escape through the opening at *c*.

These bellows are only used by hand, or at most in small forges and organs. If a very powerful and intense stream of air be required, as, for instance, in smelting furnaces, &c., large blowers are employed, driven by steam or water power. These form a kind of condensing air-pump, excepting that they have an escape aperture. The most convenient and generally employed of these contrivances is the *cylindrical blower* represented in *pl.* 19, *figs.* 2 and 3. A is a cast iron cylinder, in which a piston, *cc*, fitting air-tight, may be moved up and down by a piston rod, *a*. Through the upper valve at *b*, and the lower at *d*, the inside of the cylinder is in communication with the external air, while the valves at *f* and *g* unite the cylinder with a four-cornered box, E. At all the openings are valves, of which those at *b* and *d* open inwards; those at *f* and *g*, outwards. When the piston descends, it closes the valve at *d*, while the air penetrates through the opening *b* into the upper part of the cylinder. The reverse takes place

when the piston rises. The air compressed in the box E, which serves as a reservoir, pours out through a tube attached at *m* to the fireplace.

To maintain a uniform stream of air, which is necessary in most smelting processes, *regulators* of various forms are employed. One of these, represented in *fig.* 4, depends for its action upon the pressure of water introduced, whence it is called a *water regulator*. It is very similar in its nature to the gasometer previously described: E is a box consisting of iron plates screwed together, containing from 30 to 40 times the volume of the cylinder of the blower, and into which the air pours from the cylinder through the tube D, escaping again through C. The entire box, E, is suspended equably in a cavity of masonwork or iron plates, so as not to touch its bottom. This cavity is partly filled with water, which completes the box E. In a state of equilibrium, the water will stand at the same level in both vessels; when, however, air is introduced into E from the blower through D, exit through C being for the time prevented, the surface of the water in E must become depressed to *rr*, while it rises to *vv* in A. Upon the difference of these two surfaces depends the amount of pressure experienced by the air in E, and consequently the force of escape through C; which escape is rendered uniform by the regulator. If the pressure is to be increased, all that is necessary is to increase the height of the water in A by fresh additions.

It is often necessary to observe and measure the pressure existing in the interior of the cylinder, as, for instance, the case might readily occur of an escape-valve refusing to do its duty, which might result injuriously, either in a bursting of the cylinder, or some other accident. Such results can only be avoided by being able to examine at any time the interior pressure. For this purpose, the *wind measurer*, a kind of manometer, has been invented. This is represented in *pl.* 19, *fig.* 5. It consists of a tin box, air-tight and partially filled with water, through whose bottom passes a tube, *a*, which can be attached to the blower by a male screw, and through which, therefore, a communication is established between the blower and upper part of the box. With the lower part of the latter communicates a glass tube, *b*, provided with a scale, in which, at the beginning, that is, before the blowing commences, the water poured in through an opening in the cover of the box must stand at the zero of the scale. If, now, by the action of the blower, the water in the upper part of the box becomes compressed, that in the tube ascends, and by its height indicates the pressure of air in the blower. At *d* a tube is attached for letting out the water in the manometer.

We will here only add a few words respecting the laws which come in application in the escape of air. As a general rule, the same laws apply to gaseous as to liquid bodies, namely, that the velocities of efflux are as the square roots of the heights of pressure, although the latter cannot, as in the case of liquid, be determined directly by experiment. In the case of liquids we had to do with a pressure column of the same nature and density as the escaping liquid; here, however, the pressure is produced by a column of air having neither a uniform density nor a fixed limit. In general, however, the pressure exerted upon a vessel in escaping is measured by a mano-

meter with a water or mercury column, and the amount of pressure estimated by the height of the column.. Supposing air subject to the pressure of one atmosphere to pour into a vacuum, we know that the pressure of one atmosphere holds in equilibrium a column of water 32 feet or 10.4 metres in height, and that the density of air is 770 times less than that of water; consequently, a column of air having this density throughout, must be 8008 metres high to maintain in equilibrium the pressure of the atmosphere, and in this case the velocity of discharge would be $= \sqrt{2 \times 9.8 \times 8008} = 396$ metres, = nearly 1300 feet.

If the space into which the stream is to pass already contain air of a slight tension, the tendency to escape is dependent upon the difference of the two tensions. Expressing by H the height of a column of air representing the difference of these tensions, and having the density of the more strongly compressed air, the velocity of discharge will be $= \sqrt{2gH}$, where g indicates the velocity at the end of the first second (9.8 metres, or about 31 feet: see page 202) [Physics 28]. The factor, H, must be developed by a series of inferences and calculations. Suppose gas to escape into the open air from a gas-burner, the pressure in the gasometer is determined by a column of water of measured height which we may call h; it is then only necessary to ascertain how high a column of a gas like that consumed in the gasometer will be necessary to hold this pressure of water in equilibrium. If we had to deal with air of mean atmospheric pressure, then for the column of water, h, a column of air of $770h$ may be taken; as, however, the gas is more condensed, the column of air need not be so high. Now, however, atmospheric air is compressed by a column of water thirty-two feet high, which pressure may be called b, while the gas has to sustain a pressure of $b' + h$, where b' indicates the height of a column of water at the barometric pressure of the same instant. The density of air at the mean pressure is therefore to the pressure in the gasometer, as $b : b' + h$; the gas is therefore $\frac{b' + h}{b}$ denser than atmospheric air, and, instead of $770h$, we must take $\frac{770hb}{b' + h}$, this being the value of H, and consequently $c = \sqrt{2g \frac{770hb}{b' + h}}$; the quantity, M, discharged in t seconds through an aperture whose cross section is m, will then amount to $ft \sqrt{2g\left(\frac{770bh}{b' + h}\right)}$. Nevertheless, here, as in the case of liquids, a considerable deduction must be made in practice, and the above result must be multiplied by a definite fractional factor. In water this is 0.64, and is constant; in gases it is variable, and can only be obtained by trial. Cylindrical and conical escape-pipes increase the amount of discharge.

The laws of friction and of lateral pressure in the conducting pipes agree as to the rest with what has been determined for liquids; and the phenomena of suction likewise take place in the motion of gases, just as in the flow of liquids.

ACOUSTICS; OR THE THEORY OF SOUND.

a. General Observations; Wave Motion.

Before entering upon the theory of sound itself, it will be necessary to premise some observations upon the motion of waves in general, as these play a great part in this section of Physics.

Imagine a body making oscillations similar to those of a pendulum, in which, however, the relative positions of the different parts do not, as in the pendulum, remain the same; then these parts, to return to their original equilibrium, must likewise take up an oscillatory motion which differs from that of the pendulum, in that the mutual position of these particles changes every moment. Two conditions of things may here occur: either all the parts oscillate at the same instant and in the same time, or the oscillations may be propagated in different parts successively, so that one part may begin its motion when the preceding has ceased. The first case presents itself in a steel spring fastened at one end, or in a string attached at its two extremities; in the second case waves are produced, and an illustration furnished when a stone is dropped into still water. All these vibratory motions admit of various modifications in extent and rapidity; if they exceed a certain degree of velocity, their combined action produces wave movements in the surrounding medium, which are propagated to our organs of sense, and produce peculiar impressions upon them. These vibrations, within certain limits, produce waves in the air, consisting of alternate condensations and rarefactions, and are perceptible to our ears as tones; light is the impression which a vastly more rapid vibration of particles produces upon our eyes, by inducing wave motions in a peculiar elastic fluid, the ether. It will therefore be necessary, as wave motion serves to propagate vibrations, to begin with that, and first to consider water waves, whose formation and conditions may be directly observed by us.

If a stone be dropped into water, it forms concentric circular waves, which consist of alternate elevations and depressions, in whose advancing motion the individual particles of water do not take part, as is shown by the fact that a floating body, although rising and falling, yet remains in the same place on the water. When regular waves are formed, the single particles of water on the surface, during the advance of the wave, describe curves returning into themselves, which are only closed when the succeeding wave is higher or lower: in cases of great regularity the curves are circles. Let us suppose that a motion, assumed to be perfectly regular, is propagated from one side to the other over a series of water particles, twelve for instance, then, when the first particle has completed its circular motion, the twelfth will be just beginning, and each intervening particle will be just one twelfth of its course behind the preceding. By means of these different motions is produced the curvilineal form of waves, and wave arcs are formed whose summits are where the water particle has completed its cir

cuit, and begins a new one. The distance between two water particles in the same conditions of oscillation is called a wave length, and these particles have then precisely equal oscillations, while those lying on the half wave length are in precisely opposite conditions of oscillation. Other conditions occur where the motion is not perfectly regular, as then the paths cease to be circular, and frequently become elliptical, with the long diameter sometimes horizontal, sometimes vertical. If the horizontal diameter = 0, the particles oscillate only at right angles to the direction of the waves, and it is motion of this kind that propagates waves in a stretched cord. A cord wave, when reaching a certain point, is thrown back again, and may traverse the same route several times: two waves again may easily meet, and by their combination produce a standing wave.

Let us now examine the character of the motion of a cord or string during a standing vibration. A standing vibration of a string may be readily produced by taking one not too tightly stretched, and, drawing it out of the position of equilibrium, letting it go again. All parts will be simultaneously on one or the other side of the position of equilibrium,—they will be simultaneously at their maximum of distance from this position, the amplitude of oscillation only being different for each particle. The oscillations of a tense string when brought out of its equilibrium, or when disturbed by a bow drawn across its middle, are of precisely the same character; they are so rapid, however, as to be indistinguishable to the eye: they therefore give a tone. The standing vibrations in a string can also be shown by attaching one end, and with the other held in the hand, describing small circles, in which case the vibrations will form a great circle in the centre: accelerate the motion of the hand, and there will be in the middle of the string a point of rest, each half swinging as the whole did previously. *Pl.* 19, *fig.* 51, represents these vibrations: *a* is the point of rest; the nodes, *ab* and *ac*, are the vibrations or bellying of the string. Two nodes and three bellyings even may by a still greater velocity be produced. There is a better mode of observing these nodes than the one just mentioned: take a stretched string, *bc* (*fig.* 52), and place a rest at *a*, so that $ab = \frac{1}{3} bc$, and draw the bow of a fiddle across the smaller portion; the other portion will be set in vibration, and in such a manner that at the middle point there will be a second node, and consequently two bellies formed. The position of the node may be shown by its being the only point along the string where a small bit of paper laid across will not be thrown off by the vibrations of the string. Place the rest at one quarter of the length of the string, and there will be in the larger portion two nodes and three bellies.

It is not strings alone that vibrate in this manner: plates, bells, and smaller bodies may also be set in vibration, and exhibit certain vibration nodes. To cause such bodies to vibrate, the apparatus, *pl.* 19, *fig.* 62, is employed, in which the plate of wood, glass, or metal, is laid upon the lower small cylinder, and then firmly fastened by means of the upper screw and a piece of cork. Set the plate into vibrations, which is best done by drawing across it a fiddle-bow, and the nodal lines and vibrating portions will be rendered evident by strewing over the plate fine sand or lycopodium. The

powder is thrown up into the air when it falls upon the vibrating portions, and finally accumulates on the nodal lines, or lines of no vibration. They remain constant, therefore, and form the well known sound figures, first discovered by the eminent natural philosopher, Chladni. By taking sand moistened with gum water and finely pulverised, and placing a damp piece of paper on the plate, the figures may be removed and rendered permanent.

Different figures result with a variation of the point of support of the plate, the rapidity of the vibrations, and the point of application of the vibrating cause; of the hundreds fixed by Savart in the manner described above, we shall represent a few (*figs.* 63–74). The simple cross is produced when the plate is fastened in the middle and intonated at one corner; if the latter take place at the middle of one side of the plate, the cross (*pl.* 19, *fig.* 71) is formed, &c. Other of the four-sided figures represented, are obtained by preventing the vibrations of one or more points of an edge of the plate, in which case several nodal lines are formed; symmetrical figures, however, are always produced, as the vibration which is hindered on one side ceases also in the corresponding parts of the other three. Triangular and polygonal plates give similar results. In circular plates very different tones may be produced, and each tone has its proper figure. Here may be distinguished three kinds of figures: diametral, concentric, and mixed. The diametral figures are obtained in a manner similar to the method employed for *figs.* 63 or 71, and the nodal lines are then radii. In the concentric the nodal lines form concentric circles, and are obtained by piercing the centre of the plate, drawing the hair of the bow through the hole, and thus producing the intonation. The plate then needs only to be supported in some of the points through which the nodal lines are to pass. The figures of the mixed system consist of diametral and concentric more or less curved lines, as seen in *figs.* 75–83, and are obtained by fixing the plates in the centre, and pressing the figures upon the points through which the nodal lines are to pass. Stretched skins or membranes act in the same manner as the plates, and Marx has exhibited the sound figures of these by means of his instrument, the Eoline.

Normal vibrations occur in bells as in plates; and here also nodal lines are formed, which are, however, sometimes exceedingly irregular. To render these vibrations visible, we make use of a large wine-glass with a foot (*fig.* 84), filled with water or mercury, and intonated on the edge. There are then formed two very evident diametral nodal lines, between which the fluid remains in constant vibration, sufficiently violent at times to throw up drops into the air.

In vacuo nodal lines are obtained which do not always agree with those formed in the air, particularly when the powder employed is very light, as lycopodium.

Plates, bells, &c., which do not possess equal elasticity on all sides, likewise form peculiar figures, which, however, cease to be strictly symmetrical.

b. Transmission of Sound through the Air.

By the vibration of a body a wave motion is communicated to the surrounding air, and this it is which brings the tone, arising in the vibration, to our ears. Not air alone, however, but every elastic medium, can propagate sound; in a vacuum this propagation does not take place. Of this fact we may be convinced by placing a small bell, moved by spring clockwork, and isolated by being set on a woollen mat, in the receiver of an air-pump. Cause the hammer of the bell to commence striking, and with an increasing rarefaction of the air, the sound will become fainter and fainter, until it disappears almost entirely. Re-admit the air, and the sound will be again audible, becoming more and more distinct. Saussure found, that on the summit of Mont Blanc, a pistol-shot made only an inconsiderable sound; and Gay Lussac noticed, that when at a height of about 3000 feet in a balloon, his voice became less powerful. The loudest sound does not pass beyond the atmosphere, and terrible explosions might take place on the moon without our hearing anything of them. Water transmits sound very well, since divers hear at the bottom of the water, the voices of persons speaking on the shore.

The manner in which the vibrations of sound are propagated through the air, may be best understood by supposing an open tube, *bdtt'* (*fig.* 49[a], *pl.* 19), in which, from *t'b*, a piston may be moved quickly backwards and forwards. Suppose the length of the tube to be divided into a number of parts, equal to the length of the play of the piston, about in *s, a, b, c;* then when the piston is forced into *a'*, the air between *a'p* will fall into a vibratory motion, and this motion will be transmitted to the layer *ps,* when the piston has reached *p,* and will pass over into the second half to *b,* when the piston has finished its advance and commenced its return. This motion cannot, however, be uniform, for previously mentioned reasons, and we obtain the velocity in the individual parts by describing a semicircle above *sa,* the length of the play of the piston, dividing this semicircle, as at *x'* and *y',* into equal parts, and letting fall the perpendiculars, *xx'* and *yy'*. The motion must, from the elasticity of the air, be transmitted successively to all the strata, while, if the air were inelastic, the piston would drive out all the air before it. From these considerations we may readily understand, that during the ingress of the piston, the air in *bs* becomes compressed before the motion is transmitted to *sa.* When the piston begins its return, the compression is propagated to *sa;* the strata between *s* and *b,* however, enter upon a retrograde motion, and when the piston has reached *b* again, occupy their old position. With a new action of the piston, the first vibration passes over to *ab;* while the layers between *a* and *s* are making their retrograde motion, those, however, between *s* and *b* are compressed, &c. Sound waves are consequently formed, each of which has the duration of a forward and backward motion of the piston, and consists of a rarefied and a condensed part, which then corresponds to the wave valley and wave elevation.

The velocity with which the waves are propagated through the air is independent of the velocity of the action of the piston and of the individual strata of air; as, however, experiment has shown that the velocity of propagation of air waves is independent of the time in which each individual part completes its oscillation, and the wave length is the distance by which the wave advances while a single layer makes a complete vibration, the wave lengths must increase in the same proportion as the time of vibrations of the individual particles of air. Thus, if the piston require triple or quadruple the time to make a complete backward and forward motion, the wave lengths will be three or four times as great.

We have thus considered the transmission of air waves in tubes: in the open air they must be transmitted in precisely the same manner in all directions.

The impression produced upon the ear in this motion of air waves is very different according to their character. If the motion be produced by a single blow, and this not repeated, as in a pistol shot, where thus the air is suddenly and powerfully condensed, and then advancing as before mentioned, we hear a *report;* in regularly successive vibrations we hear a *tone;* and if the successive vibrations become more and more irregular, we have a *noise.* The tone itself will be higher as the length of oscillation or the wave length is shorter: it becomes stronger or more intense as the amplitude of oscillations in the sounding body is greater, for so much the greater is the degree of condensation and consequent rarefaction of the air waves.

The velocity with which tones are transmitted through the air is constantly the same, whether they be high or low, strong or feeble. Experiments were instituted in 1822 by the *Bureau des Longitudes*, accurately to determine this velocity, whence it resulted that sound travelled 340.88 metres, or about 1050 Paris feet in a second. During these experiments the thermometer stood at 60°F., the barometer at 756.5 millimetres, and the hygrometer at 78°. Experiments recently performed by Sir John Herschel give 1125 English feet per second as the rate of transmission at 62½°F. Above 62½°F., each degree adds 1.14 feet to this velocity, and below this temperature the velocity is diminished in the same ratio.

As light travels faster than sound, it will be readily understood why the flash of a gun may be seen before hearing the report, and the lightning be observed long before the thunder reaches us, the interval depending upon the distance at which the phenomenon takes place. But for the numerous corrections required by the varying temperature, density, and hygrometric condition of the air, it would be an easy matter to determine the distance by this interval.

c. Reflection of Sound.

Whenever a sound attempts to pass from one medium into another, as from air into water, or from one gas to another, it experiences a partial reflection; this, however, is strongest when the sound strikes against a solid

body; and when the body possesses very little elasticity, the reflection may be total. In this latter case, the law that the angle of reflection is equal to the angle of incidence prevails; in the former, while one part is reflected according to the same law, the remainder is transmitted.

Upon this law of reflection depends the phenomenon called the *echo.* When sound strikes the reflecting surface at a right angle, it is thrown back again, and the quickness of the return depends on the distance from this surface. If this amount to 1125 feet, then the sound will complete its advance and return in two seconds: the tone will then be again heard after this time. As many syllables will be reflected by the echo as can be spoken in this time: the number may amount to seven or eight. The number of syllables repeated by an echo does not depend, then, so much upon rapidity of utterance, as upon the distance of the reflecting surface. At sea it has been found that even clouds have served as reflecting surfaces, so that it would seem as if the surface struck need not necessarily be a solid body.

An echo often repeats the same syllable several times, this being produced by successive reflections of the same tone from different surfaces, or from two surfaces parallel to each other. Thus, from the top of the Rosstrappe in the Harz, the discharge of a pistol gives a manifold echo resembling rolling thunder.

Here belongs the echo which returns a tone to a given spot, so as to be inaudible at a very short distance from it. Suppose an elliptical dome (*pl.* 19, *fig.* 93), *aba'*, whose foci are *f* and *f'*. A word spoken at one focus will be reflected to the other, and will be inaudible in the space between *f* and *f'*; a light whisper will be understood even if the distance between these points amounts to 80 or more feet. This phenomenon depends upon the fact that if lines be drawn from *f* and *f'* to *i* and *i'*, and any other points of the curve, these lines drawn to any one point will always make the same angle with the perpendicular at this point. Another phenomenon, such as occurs in the Rathskeller in Bremen, where the ticking of a clock in one corner of the arch is heard in the other, depends upon the fact that the flutings used to ornament the arches supply the place of tubes, which propagate sound better than the open air.

The construction of rooms for public speaking or music, involves to a great extent the principles of the reflection of sound; into all such constructions the parabola enters, or should enter, very largely, as a sound produced in the focus of a parabola is reflected in every direction with the greatest possible uniformity.

d. Formation of Musical Tones.

If we have a tube closed at one end, at the open end of which a sound wave enters, this latter will be transmitted to the other extremity and there be reflected. Standing vibrations may then be formed in the tube itself by the opposite action of the reflected and re-entering wave, as all the single strata in the tube begin their motion at the same time, attain at the same

time the maximum of their velocity, and likewise reach simultaneously the terminus of their path, again to recommence in an inverted order. In standing wave vibrations of this character, the air is condensed uniformly in the tube when the single strata of air pass their position of equilibrium with the maximum of their velocity: if the particles have arrived at the extreme points of their course in their oscillation towards the closed end of the tube, the greatest condensation here takes place. If, now, they begin to return after half an undulation, a rarefaction takes place at the closed end of the tube; at the open end there is neither a marked condensation nor rarefaction. When the tube has an opening in any part of its length, the formation of a standing wave experiences an interruption, since in the moment of greatest condensation the air can escape, and can enter during the rarefaction; this circumstance operates less as the aperture is nearer the open end, since here neither the condensation nor the rarefaction is so great as to exercise any material influence. Cutting off the tube at this place would produce the same effect, and the sound waves would thus be no longer than from the beginning of the tube to the orifice.

The formation of a standing air wave depends, then, upon the relation between the length of the tube and the wave length of the incident tone; it is also essential to the formation of a standing wave in the tube, that close to the bottom the amplitude of oscillation shall become almost nothing; that there the alternating condensations and rarefactions shall take place, while at the open end they must not occur. To this end the distance of the opening from the bottom of the tube must be $\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{4}$, $\frac{7}{4}$, &c., of a wave length, and we then obtain in the tube vibration nodes similar to those which we have already found to exist in strings and plates.

To put the air in a closed tube into such vibration, we need only bring an oscillating body near the open end of the tube, which shall give such a tone that the length of the tube has one of the above proportions ($\frac{1}{4}$, $\frac{3}{4}$, &c.) to the wave length. If, for example, a vibrating tuning fork be placed about two inches above the open extremity of a glass tube closed below, then if the latter is of the proper length, the two will become resonant, in which case the strata of air contained in the tube will be put into a condition of standing vibrations. By this means the tone of the tuning fork is increased considerably in intensity. If the tube be too long for the sounding body, it may be shortened to the proper length by pouring in water. Instead of the tuning fork, one of the glass plates used in the production of sound figures, or a glass bell, may be intonated with a fiddle-bow before the opening. Savart constructed for this purpose the apparatus represented in *pl.* 19, *fig.* 92. It consists of two wide tubes, movable one within the other by means of a screw, by which the sound tube may be lengthened or shortened at pleasure. Before the opening of the tube stands a glass bell which can be sounded by means of a fiddle-bow. Bringing the tube to the proper length, the sound of the bell will be much increased in intensity; removing the bell from the vicinity of the tube, by sliding it along the groove in the base of the apparatus, the tone will become remarkably thinner.

The air within a tube may also be put into standing vibrations by causing a current of air, flowing past the tube, to break against the edges of the opening, waves being thus produced which are reflected from the bottom, and interfere with those subsequently created. In narrow tubes the air may be set into standing vibrations by bringing the open end of the tube against the lower lip, and blowing into it obliquely against the edge. The tones will be deeper in proportion to the length of the tube, and inversely. The so-called Pan's pipe is an illustration of this condition of things.

Upon the principles just explained depends the construction of organ pipes, which are made principally of wood, in which case they are four-cornered, or of tin, when they are made cylindrical. *Figs.* 53 and 54 represent the form of the wooden, and *figs.* 55, 56, and 57, that of tin pipes. Such a pipe consists of the foot or pedal, *p*, the labium or mouth-piece, *b*, *b'*, and the tube. The pedal is hollow and sharpened to a cone below, to place it in the sound-board from which the pipe receives the air, which is to produce in it the vibrations of sound waves; above the widest part of the pedal is placed a bridge, *l*, which contracts the opening to a very fine slit, and thus directs the entering column of air against the sharp edge of the labium. The pipes themselves are supplied with air by means of a pair of bellows, a very convenient apparatus for which is exhibited in *pl.* 19, *fig.* 58. Between the feet of a small table, *ss'*, is attached a bellows, set in operation by the foot-board, *p*, and forcing its wind into the superincumbent wind box, which sends it through the tube, *ff*, into the upper sounding-board, *cc*. As this wind box, by continued motion of the bellows, will soon become full, if little air is used, a lever connected with a valve in the wind box strikes against a pin attached to *ff*, and thus lets out the superfluous air. The rod, *tt'*, serves to give greater pressure to the wind box where a sharper current is required. In the upper floor of the sound-board are several holes, *oo'*, generally twelve, in which pipes may be inserted. These holes are always closed with valves, which may be opened by a register at *hh'*, upon which the air can enter into the pipes and cause them to sound. With a feebler wind the same pipes give a lower, and with a stronger a higher tone.

Not covered tubes alone, or those closed at the upper end, can be thus intonated, but also those open above, and in precisely the same manner. In these the short and narrow tubes will always give the higher tone. Another method of employing open tubes consists in generating hydrogen gas in the apparatus represented in *fig.* 91, letting it escape through a fine mouth-piece, and after setting it on fire, placing a tube, *ab*, over the jet.

Standing vibrations arise in an open tube, from the circumstance that a greater condensation takes place in the middle, the particles of air not being able to escape; as soon as this condensed portion comes to the open end of the tube, the particles expand, thus producing a rarefaction, which, sent back, traverses the tube in the opposite direction. As, however, at the open end a condensation and a rarefaction coincide, no vibration nodes can here occur, these necessarily existing in the inner portions of the tube; if, therefore, the deepest tone of an open tube is to be equal to that of a closed, the former must be twice the length of the latter.

If holes capable of being closed by a slide, are made in different parts of an organ pipe, it may be shown that the tone remains unchanged if the opening exists at a belly, while another tone is produced if the opening is made at a vibration node.

However little the influence exerted upon the tone of a pipe by the direction in which the current of air strikes the mouth-opening, so much the more considerable is the effect produced by the shape of the labium, and the height of the air-hole.

The walls including a vibratory mass of air exert a great influence upon the tone, and a pipe constructed of poor tin, or of soft or resinous wood, gives constantly a smothered feeble tone; even moisture upon the wood produces the effect of lowering the tone.

With regard to the musical notes produced by organ pipes, let us call that tone produced by a pipe four feet long, the fundamental note C. If we examine the pipes whose tones harmonize with that of C, we shall find that the rapidity of oscillation of notes produced by them, stands in a simple relation with that of C; the pipes will therefore be $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{5}{6}$, &c., the length of C. A pipe of half the length gives then the octave; that whose length is two thirds, and which makes three oscillations to two of C, is the fifth; three fourths the length gives the fourth; four fifths of the length gives the major third; and five sixths the minor third. The intermediate tones are obtained by taking one of the pipes in question as the fundamental tone and finding its accord. Thus we obtain for the G accord the fifth D, if we take a pipe two thirds the length of G, and the major third H with a pipe of four fifths, and the minor third B with one of five sixths the length of G, &c.

The deepest tone in music is that C given by a covered pipe of sixteen feet in length, or an open one of thirty-two feet. We know, however, that for the deepest note of a covered pipe, its wave length must be exactly one fourth of the wave length of the tone; in the open air, therefore, the wave length of this amounts to 64 feet. Sound travels about 1050 German feet in a second, hence it follows that to produce this deepest note there must be $\frac{1050}{64}$ or 16.4 oscillations in a second (more correctly, perhaps, $\frac{1125}{64}$ or 17.5). We obtain the number of vibrations necessary to bring out the deepest tone of any covered pipe, by dividing 1050 by four times its length. Thus the C's forming the six lower octaves make respectively 16.5, 33, 66, 132, 264, and 528 vibrations in a second. The greatest number of vibrations observed in a second amounts to 24,000; the tone thus produced is, however, scarcely audible: the deepest audible tone is that produced by 7.8 vibrations. Still higher and deeper tones may perhaps be produced and rendered audible by artificial means.

The length of pipes gives a ready method of determining the number of vibrations: this is nevertheless not entirely exact, and Cagniard de la Tour has invented a special apparatus by means of which the absolute number of vibrations in a tone can be accurately determined. This instrument is repre-

sented in *pl.* 19, *figs.* 59—61, where t, t', f, f', is a round box of brass about two or three inches broad and one inch high, whose upper surface is perfectly plane and well polished; there is an opening in the middle of the bottom ff', into which the air tube, gg', is screwed. In the bottom, tt', represented from above, and laterally in *fig.* 60, a number of holes equidistant from each other are bored, their interspaces being somewhat greater than the diameter of the holes, which generally amount to ten; pp' is a movable plate, ground upon the plate tt', and provided with holes corresponding in size, number, and position, with tt', so that by turning pp' about its axis, x, on tt', all the holes may be simultaneously opened or closed. At the upper extremity of the axis x there is an endless screw, catching in a wheel, rr', of 100 teeth; ec' is a second wheel of 100 teeth, standing in such connexion with the first that it completes only one revolution while the first makes 100, an arm on the axis of the first wheel pushing the second forwards by one tooth at each revolution. The axes of these two wheels carry indices, which mark on the dials attached to the side plate (as represented in *fig.* 61) the revolutions and their fractions. To start this part of the machinery, or arrest its motion at any moment, the axis of the wheel rr' is united in such a manner with the buttons b and b', that this wheel can either be caught in the endless screw or separated from it. The apertures in the plates tt' and pp' are directed obliquely to the surface, so that the air rushing through gg' is capable of causing a rapid rotation of the plate pp'. Suppose, now, that in the movable disk there are ten holes, and in the other only one, then this would be opened and shut ten times in a revolution of the plate: there thus arise ten complete sound waves in one revolution, of which there may be 1, 10, 100, &c., in a second, so that all the tones may thus be produced. The lower plate has, however, ten holes; and as each one exerts its influence, there is produced a strong lasting tone.

To count vibrations with this instrument (called by its inventor the Siren), place upon the sound-board (*fig.* 58) a concordant pipe, as the *a* of the common tuning fork, and near it the siren in another hole of the sound board. Allow the air to enter, and regulate the pressure upon the wind box by the rod t, until the two are in unison; then couple the wheel of the siren, and allow it to revolve a certain time by a seconds-watch. Stop the motion of both watch and siren, and from the latter may be obtained the entire number of revolutions, and from the former the number of seconds; comparing the two will give us the number per second. We shall then find that in one second 440 revolutions have been made, which is really the number of vibrations for the tone *a* of the tuning fork.

The vibrations of strings are much too rapid to admit of their being counted; they are even visible only in the longest and deepest strings. It was known very early that the tone of a string was higher the more the string was stretched, or when it was shortened. It was not possible, however, to indicate by means of calculation the connexion between the tone of a string, its tension, its length, and the rapidity of its vibration. The eminent philosophers, Taylor, the two Bernouillis, d'Alembert, and Euler,

occupied themselves with the investigations of this relation; Lagrange, however, was the first fully to elucidate it. The propositions established by him are the following: 1. The number of vibrations of a string is inversely as the length, that is, half the string makes twice the vibrations of the whole, &c. 2. The number of vibrations is proportional to the square root of the stretching weights, that is, four times the weight produces twice the number of vibrations. 3. The number of vibrations of cords of the same material is inversely as their thickness, that is, a string half as thick as another makes twice the number of vibrations in the same time. 4. The number of vibrations of strings of different material is inversely as the square roots of their densities: thus, taking a string of copper whose density is 9, and a string of catgut whose density is 1, their diameters and lengths being equal, the latter will make three vibrations in the same time that the first makes one.

The *Monochord*, invented by Savart, and represented in *pl.* 19, *fig.* 50, is used for determining the laws of oscillation of stretched strings, and their tones. It consists principally of a hollow box, *ss'*. At *c* is a bridge with slits in which the strings are fixed, which then pass over the two bridges, *f* and *m*, and beyond *m* may be stretched by weights. A third bridge, *h*, may be moved along under the strings without touching them, and any point of the string may be pressed down upon it by means of a binding screw. By moving along this bridge, all the notes of an octave may be produced, and we shall find that the lengths for a fundamental note $c = 1$ are in the following proportion: $c = 1$, $d = \frac{8}{9}$, $e = \frac{4}{5}$, $f = \frac{3}{4}$, $g = \frac{2}{3}$, $a = \frac{3}{5}$, $b = \frac{8}{15}$, $c = \frac{1}{2}$, the same ratio that is found to exist in organ pipes. These ratios confirm, at the same time, Nos. 1 and 2 of the propositions just adduced; for to obtain, for instance, the octave of the fundamental note by tension, it is necessary to attach four times, and for the fifth, nine times the weight, &c.

e. Of Longitudinal Vibrations.

Strings and rods have not only transverse vibrations, such as we have already considered, but they also vibrate longitudinally, like the air inclosed in a tube. This is shown by rubbing a glass tube longitudinally with a damp finger, or drawing a fiddle-bow across it at a very acute angle. The same takes place in massive rods of glass, metal, or wood, although here it becomes necessary to make use of a piece of rag, sprinkled with powdered rosin. It is, however, more convenient to make use of a so-called sounding rod, namely, a short glass tube whose axis is made a continuation of that of the body to be set into vibration. Vibrations produced in the first by rubbing with a damp cloth, will then be communicated to the second, and the two will vibrate together. Straight rods held in the middle and free at the extremities vibrate like open tubes; and all rods of equal length, whatever be their thickness, give the same tones. Nodal lines are also

formed on the rods, consisting of the points of rest formed by the individual molecules during their motion produced by the vibrations. These nodal lines form peculiar curves, which exhibit a certain similarity to a greatly elongated helix, forming a node at each revolution. The inner surface of a vibrating tube presents nodal lines similar to those of a rod. In prismatic rods the nodal lines are more complicated.

f. Tongue Work and Reed Pipes.

Any thin plate set into vibration by a current is called a *tongue*. Thus, in *pl.* 19, *fig.* 95, *ll* is a tongue, which, by means of a small screw, is so attached to a plate that it can vibrate in the little aperture, *nbcd*, without touching the edges. The plate may be of brass or zinc; the tongue, *ll*, should be a very thin elastic slip of brass. The current must be directed against the free end of the tongue, *ll;* sounding vibrations are thus produced by the alternate opening and closing of the aperture, whose length depends upon the number of vibrations of the tongue. The accordeon is a combination of several tongues, yielding the successive notes of the scale; these are placed upon a sound-board, and played upon by air from a bellows. Each tongue has its valve, which may be opened by a stop, and the air thus admitted to produce vibrations in the tongue.

The tongue-work in an organ has a similar construction, although the attachment is somewhat different. *Fig.* 97 represents the arrangement on a large scale. The tongue-work consists of a pedal, *p*, in which is a hollow channel, which appears above as a round hole. This channel is closed by the plate *r*, in whose opening is the tongue *l*, to be vibrated by the air passing through the channel. To tune the tongue its length must be changed, for which purpose there is a tuning-wire passing through the pedal, and by its two extremities pressing the tongue against the plate. The vibration of that part of the tongue between the plate and the wire is thus prevented.

This tongue-work is combined with the pipe, *t* (*fig.* 96), in such a manner, that the air entering through the pedal of the pipe presses against the tongue, setting it in vibration. It then escapes through an opening in the head, *t'*. When the pipe is used, by way of illustration, a glass plate lies before *ab*, to exhibit the action of the tongue. Sometimes, and generally in organs, the tongue-work is placed in the pedal, and the tube is then directed upwards.

The form of the tube gives character to the tone; thus the trumpet works have tin tubes widening above, &c. In such tongue-work, however, the vibrations of the tongue depend upon the motion of the column vibrating in the long tube, and the tongue is more vibrated than if it made entirely independent vibrations.

g. On the Beats of Tones.

If two tuning-forks of very nearly the same pitch, or two strings or pipes of almost precisely the same tone, be sounded simultaneously, we shall hear a variation of the tone, consisting in an alternate increase or diminution of its intensity. This is caused by the fact, that both sounds are produced by undulations of very nearly, but not quite the same rapidity, so that at one time these will come together in the same phase of vibration, and at another time in opposite phases. In the first case the intensity will be double that of a single sound; in the latter, no sound whatever would be perceived but for the momentary persistence in the ear of the sound of the instant previous. The tone will consist then in a gradual increase or diminution between these extremes. The greater the difference in the rapidity of undulation, the more frequent will be these *beats;* when the two instruments are in unison they cease entirely. Any number of strings may thus be brought into unison by tuning until the beats are found to have disappeared altogether. When two sounds are heard, of which the vibrations stand in a simple ratio to each other, as of two to three, three to four, or four to five, and in which the coincidence of two impulses or undulations recurs with sufficient frequency, a third sound is produced by this coincidence, always deeper than the primary notes, and generally the fifth or the octave below the lower of the two. These are called tones of combination, or the accessory sounds of Tartini, and must not be confounded with harmonic notes.

h. Sound in various Media.

Sound diffuses itself through all ponderable matter, although with various velocities. Newton gave an expression for the motion of sound in the air, which was much too small, being but about five sixths of the actually observed velocity; Laplace explained the difference by showing that a motion of sound cannot take place but by compression of the molecules of the air, during which, in all cases, there must be a development of heat; and that then the heat, now become sensible, must influence the law of elasticity in such a manner as to bring about an acceleration in the transmission of sound. Consequently, temperature would influence the motion of sound, as we find to be actually the case. Laplace has given a formula for the rapidity of this motion in vapors and gases; according to him, $v = \sqrt{gmb\,(1 + at)\,k}$, where v is the velocity in a second; g, the accelerating force of gravity, 386.29 inches; m, the ratio of the density of mercury to that of atmospheric air, found by experiment to be 10.466, at a temperature of 32° F., and a barometric pressure of 29.927; b, the standard height of mercury in the barometer; a, the constant co-efficient of expansion, ascertained by experiment to be .00208; and k, the square-root of the quotient, which is found by dividing the number which expresses the specific heat of the air (or other gas) under a constant pressure, by that

which expresses its specific heat under a constant volume. The value of k for atmospheric air has been found to be 1.421, hence $\sqrt{k} = 1.192$, and substituting the various values in the above formula, it becomes $v = 916 \times 1.192\ (1 + .00104t) = 1092 + 1.14t$, where t is the number of degrees above 32° F. The velocity of sound in the air is therefore dependent upon the temperature, and not upon the pressure of the atmosphere. From this formula the velocity of sound in other gases may be determined, whenever the value of k is known, or k may be determined from the known velocity.

Since sound depends upon condensations and rarefactions, and such media alone can propagate it as are capable of this, it follows that this velocity of sound in fluids depends upon their compressibility. This compressibility must be obtained by direct measurement, for which purpose Oersted invented the *Piezometer*. By the use of this instrument and calculation, it has been found that in water of 54° F., the velocity of sound in a second amounts to 4630 feet; direct experiments by Colladon, in the Lake of Geneva, have given results indicating a velocity inferior to the above by less than sixty feet.

The same principle holds good in general for solid bodies. Chladni and Savart have instituted very extended experiments on this subject, and have found that this velocity is universally greater than in the air, being least, however, in whalebone, where it amounts to $6\frac{2}{3}$ times, and greatest in deal, where it is 18 times greater than that in the air.

If several solid bodies be united together, sound is transmitted with great facility throughout the whole mass, and, arrived at the extremity, the sound waves partly pass into the contiguous medium, whether fluid or gaseous; they are, however, partly reflected, and form their standing vibrations with the re-entering waves. If, however, the whole system of bodies is set into vibration simultaneously with each individual point, they lose their individual character in a great measure by this union. Upon this circumstance, among others, depends the variety of musical instruments, and this is the reason why, for example, two equally proportioned pianos may exhibit a very different character with respect to sound and tone.

Although vibrations are readily transmitted over a system of uniform bodies, solids for instance, this takes place with more difficulty when the bodies are different, as from solids to fluids or gases. Here the vibrations of the sounding body must be communicated to another, for the purpose of being increased in intensity: in other words, its vibrations are strengthened by *resonance*. An example has already been given of the strengthening of sound by a tube; another is to be found in the *sounding board*, where the vibrating strings are brought into contact with a large thin surface easily set into vibration.

In a similar manner bodies may be set into vibration by a sound wave in the air, as a door, a window, and even strings themselves. Here the sound waves in the air, started by the vibrations of a solid body, or even the original vibration of the air itself, come in contact with the body, causing it to vibrate in concert. Savart has ocularly demonstrated such sympathetic

vibrations in the shape of *sound figures*, a few of which are represented in *pl.* 19, *figs.* 85—90. These were produced by stretching a membrane over a wooden hoop or glass bell, sprinkling it with fine sand, and causing in it a sympathetic vibration, by means of an approximated tuning-fork or organ pipe. The whole series of figures here answers to one and the same tone, their different forms being produced by making the tone higher or lower.

i. Voice and Hearing.

For a description of the organs of voice and hearing existing in the animal body, we must refer our readers to the section *Anthropology*, and confine ourselves here to the consideration of the more strictly physical part of the subject, how a tone is produced and modified by the larynx. The larynx consists of four cartilages: the cricoid, the thyroid, and the two arytenoid, which are intimately connected with the windpipe and form its continuation, contracting to a mere slit, the glottis. This may be opened or closed by means of muscles attached to the cartilages forming its walls. Over this glottis lie two sack-like cavities, the ventriculi morgagnii, whose upper edges form a second glottis half an inch above the first. The whole is covered by the epiglottis, which prevents solid particles of food from entering the trachea, while passing through the œsophagus to the stomach. Various individuals, as Biot, Ferrain, and Cagniard de la Tour, have instituted experiments with caoutchouc on the formation of tones by the organs of voice; the most satisfactory, however, are those of Müller, performed with separated larynges. *Pl.* 19, *fig.* 98, represents such a larynx attached to a board, *f*, the larynx terminating with the chordæ vocales, which are stretched between *a* and *b*. *a* is one of the arytenoid cartilages (the other is behind it), *b* is the under side of the thyroid cartilage, *d* the inner membrane of the larynx which ends in the chordæ vocales, which are stretched between *a* and *b*. The upper parts are not represented, for the sake of greater clearness of the figure. If such a larynx be blown through by means of the air-tube, *u*, it gives a tone precisely similar to that of the human voice, which is strengthened, not altered, by the upper parts, which vibrate and intonate at the same time. The change of tone is produced merely by the greater or less tension of the chordæ vocales, this being effected by the action of special muscles in approximating or separating the cartilages. This motion is imitated by the strings *x* and *y*, which are loaded with weights. In this manner Müller was enabled to produce all the tones of the human organ, the higher by drawing *x*, the lower by means of *y*. In animals, the organs of voice are constructed on the same plan, but with different modifications.

The organ of hearing consists of three parts: the external ear, the cavity of the tympanum, and the labyrinth. The external ear serves by means of the concha to catch external vibrations and to convey them through the meatus externus to the tympanum, which separates the outer from the inner chamber. This tympanum is a membrane stretched over a long hoop, and to its

inner surface is attached a small bone, forming one of a connected series of four—the *malleus*, the *incus*, the *os orbiculare*, and the *stapes*. The aerial undulations are transmitted from the tympanum, by means of this series of bones, to two openings, the *fenestra ovalis* and the *fenestra rotunda*, in the labyrinth. This consists of several long excavations filled with a fluid in which the auditory nerve is expanded, passing in very fine ramifications into the *cochlea*. These various parts will be found represented in the anatomical portion of the work, to which we refer our readers.

The precise function of the individual parts of the ear is not so well established as in the case of the larynx. The tympanum, however, serves essentially in hearing by its greater or less tension, and upon its sound condition depends, to a considerable extent, the excellence of hearing. The application of the hearing tube (*pl.* 19, *fig.* 94) gives a proof of this, for in its employment the hearing is better when the sound waves received in the funnel, *cc'*, are concentrated in the tube *tt'*, and by means of the aperture *mm'* are conducted towards the tympanum. By this means the latter is set into more vigorous vibrations, and the tone strengthened without the internal portion of the ear being directly affected.

PYRONOMICS; OR, THE SCIENCE OF HEAT.

a. Expansion of Bodies by Heat.

Our knowledge of heat is limited almost entirely to its effects; of its true nature we know almost nothing. It cannot lie concealed in the interior of bodies, as in this case the refinements of modern chemical analysis would obtain some indications of its presence.

The term heat, then, is to be understood as expressing an effect; when it has reference to a cause, it will be readily intelligible from the context.

One of the most remarkable properties of heat is, that it expands all bodies: this expansion, as a general rule, increasing with the increment of heat. It is greatest in elastic fluids or gases, and least in solids.

As all bodies are expanded by heat, the amount of expansion of a body may serve to measure the degree of its heat. For a moderate range of temperature, the expansion of liquids is employed; for very elevated points, however, the extension of a solid must be substituted. Heat measures of the first kind are called *Thermometers;* of the second, *Pyrometers.*

If a glass tube with a bulb at one end be partly filled with a liquid, and if the upper part of the tube be melted together, after a vacuum has been formed in the portion not occupied by the liquid, then, by heating the ball the liquid will expand, and will rise in the tube without obstruction, owing to the vacuum above. If now the tube be graduated to a certain number of equal parts, the proportional elevation of temperature can, in every case, be determined. For filling the tube either colored alcohol or mercury may

be employed. The latter is most generally advisable, on account of its retaining its fluidity at a low degree of temperature, not vaporizing but with a considerable degree of heat. In addition to this, its expansion, without the ordinary range of temperature, is in direct proportion to the increment of heat.

The *Mercurial Thermometer* (*pl.* 19, *fig.* 7) consists of a narrow cylindrical glass tube, with a bulb blown at one end, the whole, except part of the tube, filled with mercury. The space above the mercury is a vacuum; the upper end of the tube is hermetically sealed. The filling of the thermometer is effected by atmospheric pressure. Thus, the empty tube is heated as much as possible, and the open end immersed in a vessel of mercury. A partial vacuum being formed on the cooling of the tube by contact with the mercury, a certain portion of this liquid is driven into it. If a sufficient amount be not yet introduced, the mercury already in the tube is made to boil, and, after the empty space is filled with the vapor, the tube is again inserted in the vessel of mercury as before. When the tube becomes thus completely filled with mercury at an elevated temperature, its upper end is hermetically sealed by being brought into the flame of a blow-pipe. On the contraction of the mercury by cooling, the empty space left is a perfect vacuum. The height of the mercury in the tube is measured by the scale or graduated division attached to it. This scale is constructed by fixing in the first place two points of temperature corresponding to the freezing and the boiling points of water. To obtain the former, immerse the thermometer in a quantity of finely pounded ice melting into water, and after a short time mark the elevation of the mercury upon the tube by making there a fine mark or scratch. For the latter, take a long-necked vessel filled with distilled water, and after causing the water to boil, again immerse the thermometer tube. The elevation of the mercury, after a short time, must be again marked on the tube, as being indicative of the boiling point of water. The distance between these two points, the freezing and the boiling points of water, being thus obtained, the intervening space may be divided into any number of parts. In the scale of Reaumur it is divided into eighty, and in that of Celsius or the centigrade thermometer, into 100 parts, the zero being at the melting point of ice. Graduations of the centigrade thermometer over 360° above zero, and 30° or 40° below zero, are hardly available, as these degrees are too close to the boiling and freezing points of mercury, near which the expansion and contraction are not in precise proportion to the variation of temperature.

Besides these two scales, the first of which (Reaumur's) is chiefly used in Germany, the second (the centigrade) in France, there is still a third (the Fahrenheit) employed in England and America. Fahrenheit, seeking to avoid negative quantities, obtained, as he thought, the point of maximum cold, by mixing salt and ice together; this he called zero of his scale. He divided the interval between this and the boiling point into 212 equal parts, the freezing point falling at 32°, and thus gained the advantage of having fewer fractional quantities in estimations of temperature by his instrument. There are, of course, 180 degrees between the freezing and

boiling points, so that 0° of Reaumur or Celsius (R. or C.) = 32 F. It is customary in graduating for the Fahrenheit scale, to call the melting point of ice 32°, and marking off about 70° below this point equal to 70° above it.

The measurement of temperature by means of the thermometer is exceedingly simple, all that is necessary being to bring the bulb in communication with the temperature to be measured, and marking the elevation of the mercury after it has become stationary.

As before observed, solids expand much less than liquids and gases, and must therefore be employed when high degrees of temperature are to be determined. As this expansion is of very small amount, it becomes necessary to resort to some contrivance for rendering it sensible. Now, if a rod be placed in contact with the short arm of a lever, the other being much longer, and its point serving as an index to a circularly graduated scale, then a slight expansion of the rod acting on the short arm will cause a considerable traverse of the other over its graduated scale. A better arrangement for this purpose is the apparatus of Lavoisier and Laplace, represented in *pl.* 19, *fig.* 8. A rod, *a*, of the material to be tested lies horizontally upon glass bars, one end resting against a vertical glass bar, *b*, which is suspended to a horizontal iron cross-bar, whose extremities are cemented into two massive stone pillars. The other end of the rod *a* is in immediate contact with a similar glass bar, *c*, carried by a bar, *d*, movable about its axis. To the prolongation of this latter bar, *d*, a telescope is attached, directed towards a distant scale. If, by the expansion of the rod *a*, the lower end of *c* be ever so slightly moved, the telescope will be turned, and its sight line, directed to another part of the scale, will indicate the amount of rotation. A box filled with heated water or oil is placed between the four pillars, for the purpose of heating the body to be examined, when dipped into it. This apparatus answers only for indicating temperatures below the boiling point of oil, as about 300° R = 707° F.

For higher temperatures, the apparatus represented in *figs.* 9—11 is better adapted: *f* is a strong iron plate, upon which is fastened an alidade, *ab*, turning about the point *a*. This carries a telescope, *g*, while a second telescope is fastened to the iron plate itself at *c* and *d*. A rod, *mn*, is now brought in front of the two telescopes, so that its extremities fall in the centre of the field as indicated by the cross hairs. If the rod be increased in length to *m'n*, the extremity *n* remaining fixed, the alidade must be turned until the extremity *m'* again falls in the centre of the field of the telescope *g*. The amount of this rotation is measured on a circular scale attached to the plate *f*. If the proportion between *am* and *ab* be known, then, from the arc VV' is obtained the desired extension, *mm'*, for $\frac{mm'}{VV'} = \frac{am}{ab}$. The adjusting screw, *r*, serves to shift the alidade by a very slight amount, for the purpose of adjusting the telescope *g*. For temperatures below 300°R., a copper box is used, placed upon a furnace and filled with oil. The bar to be examined is placed upon an iron support, which rests on the box. The extremities of

the bar *mn* lie opposite to two lateral apertures, closed by glass plates. For higher temperatures, the bar is placed on a support, likewise iron, in a brick furnace, in which are small holes opposite to the telescopes.

As it is in our power, from the known temperature, to determine the extension of any body, so, conversely, from the known extension of a body, the temperature to which it is exposed may be ascertained. The ordinary thermometers range only to about 360°C., or 660°F., above which mercury is converted into vapor, so that it is the melting points of such bodies only as are below this degree, such as tin, tellurium, bismuth, and lead, that can be ascertained by the mercurial thermometer. All other metals have higher melting points, and from the expansion of these it has been attempted to ascertain elevated degrees of temperature. Muschenbroek, in 1769, invented the metal pyrometer, which, in its general features, agrees with the apparatns described above for measuring the extension of a metallic bar. The pyrometer invented by Wedgewood in 1782, depends upon a different principle, namely, that of the contraction of a certain kind of clay by heat. Small cylinders of this clay were carefully measured before and after the exposure to heat, and from the difference of length the intensity of heat was determined. The great defect here, however, was, that even in the most carefully constructed cylinders, the contraction was not sufficiently uniform.

Daniell's pyrometer possesses fewer defects than any yet constructed. The indications of this instrument rest upon the difference of expansion of an iron or platinum rod, in a tube of plumbago, when extended by a great heat. A metal bar, shorter than the tube, is placed in it, and over the bar is placed a shorter bar of clay, which, placed in the opening of the tube, serves as an index by being placed upon the bar in the tube, and attached in such a manner, by means of a small plate of platinum, as to move only with a certain degree of friction.

If, now, the point be marked where, in an unheated state, the clay bar meets the tube, and the apparatus be then exposed to heat, the expansion of the metal will drive out the clay to a certain point, at which, owing to the friction, it will remain on cooling. The amount by which the clay has been protruded will give the elongation of the platinum bar. The disadvantage, in this case, is, that the extension of the plumbago tube itself cannot be determined with sufficient accuracy.

From the measured linear expansion of bodies, their cubic expansion may readily be ascertained, it being necessary only to find the coefficients for the first. The coefficient of expansion for solid bodies will be three times as great as that for these linear expansions, as these bodies are extended in height and breadth, as well as in length.

The expansion of solids by heat, and their contraction by cold, are powerful forces; for if a weight of 1000lbs. be necessary to compress a body as much as it is contracted by a diminution in temperature of one degree, then this diminution will push or pull an obstacle with a force of 1000lbs. Use has been made of this force to restore walls, by means of the contraction of iron braces, to a perpendicular from which they had swerved.

It is necessary, also, in certain circumstances, to anticipate by timely precautions acts that would arise from this property of bodies. Thus, if on a railroad the rails be laid in cold weather, with their ends in absolute contact, the summer heat will cause them to elongate, and, having no room to yield in length, to warp. The bars or rails must therefore be laid at the highest temperature, or with an interval sufficient for the greatest possible elongation. Similar cases occur in tubes for conducting steam, gas, or water, where it becomes necessary to employ special compensation pipes. The influence of temperature on pendulums and its compensation has already been referred to (p. 208), [Physics, 34]. Here belong the compensation bars, whose construction depends upon the fact, that different solids possess different expansibilities. If, for instance, two strips, one of zinc and the other of iron, be soldered together, forming a straight bar at a temperature of 20°R., then, at a temperature above this, the compound bar will become curved, and the zinc will occupy the convexity of the curve; at a lower temperature the case will be reversed, the zinc now occupying the concavity. The cause of this lies in the fact, that at equal temperatures, zinc both contracts and expands more than iron.

Upon the arrangement of compensation strips depends the construction of *quadrant* or *metal thermometers* (*pl.* 19, *fig.* 12). The strip *fgh*, consisting of copper and steel, is attached at *f*, and curves at *g* towards *h*. Against it rests, at *h*, the short arm of a lever, movable in its axis, the longer arm, *b*, being provided with the rack, *dd'*. The latter catches in a pinion moving on the central axis, whose motion is magnified still more by the needle *li*, turning on the same axis. With an increment of temperature the strip, *fgh*, becomes more curved, and the rack becomes turned in a direction from *d* towards *d'*, and with it likewise the needle serving as index. If the curvature be diminished by a bending in the opposite direction, a special spring wound about the axis produces a corresponding retrograde motion of the index. The compensation strip is so calculated, that the needle, at an increase of temperature of 80°R., shall make a complete revolution. The dial plate must be graduated separately for each instrument, by comparison with a good mercurial thermometer, and, if possible, degree by degree; as in the former the degrees are not equal, and cannot, therefore, as in the case of the latter, be described mechanically.

The most sensitive metal thermometer is that of Breguet (*pl.* 19, *fig.* 13). It consists of a spirally wound compound band of metal, formed by soldering together three thin strips of silver, gold, and platinum. This is fastened at its upper extremity to a brass arm, the lower end being free. At this lower extremity is a very light horizontal needle, whose point traverses a scale on the upper edge of a ring, supported in three feet. For protection against external influences, the apparatus is covered by a glass bell. The needle is made to turn by the unequal expansion and contraction of the silver and platinum, with change of temperature; the use of the gold is merely to unite the two other metals.

The expansion of liquids is not uniform at high temperatures, the most

even do not expand uniformly between 0° and 100° C. The elaboration of these, as well as of the actual absolute expansions, consequently always presents difficulties.

The density of a body must always be connected with its expansion, for an increase of volume always implies a decrease in density. Water, however, forms an exception to this law, for, although according to a proposition previously given, water should be of greatest density at 0° R., or 32° F., that is, at the freezing point, accurate experiment has shown, that when heated at this point it contracts, and continues to do so until the temperature has risen to 4° R., or 39°.1 F., when it is in its state of maximum density. Above this degree it expands according to the usual law. The vast importance and almost absolute necessity of this peculiarity of water will be referred to hereafter.

It has been before mentioned that mercury is most desirable for filling thermometer tubes, owing to its uniform expansion between 32° and 212° F. ; to show the difference produced by irregular expansion, we have given in *fig.* 16 the rate of expansion of mercury, water, and alcohol, at temperatures between 0° and 100° C. The lowest curve represents the expansion of mercury, and appears a straight line, owing to the uniformity of expansion. The middle curve is the expansion of water. It exhibits first a contraction (to 4° C.), at 8° C. is as at 0°, and expands then in a very progressive ratio, so that at 70° C. the ratio between W and q is almost 2 : 1. The upper curve exhibits the expansion of alcohol. To A, or 50° C., the expansion is uniform, and consequently the curve is a straight line ; then, however, the curvature increases more and more. The figure shows that water is not applicable to the filling of thermometers, and that for any other liquid than mercury, a great length of tube would be required.

We have seen that the expansive effect of heat on solids and liquids is different according to their force of cohesion, being inversely as this cohesion. In gaseous bodies, therefore, in which the cohesive force is zero, no obstacle is presented to the expansive force of heat. This must therefore be the same for all gaseous bodies, and proportional to the increment of temperature ; experiments instituted for the purpose have verified this conclusion. An *air thermometer*, therefore, may be constructed by employing air perfectly free from moisture, which may be done by passing it over chloride of calcium. For this purpose a thermometer tube is prepared, on which is accurately marked the ratio between the contents of the bulb and the volume of the divisions on the tube itself, produced by the graduations. The tube is now filled like a thermometer tube, the mercury boiled, and the tube placed in a vertical position with a tube open below, and filled with chloride of calcium, fastened to its open extremity. The mercury will escape from the tube, and in its place there will enter a quantity of air, purified from moisture, by passing through the chloride of calcium. The further entrance of air must cease while there is yet a small quantity of mercury in the tube, which must remain for two purposes, to prevent the escape of the air, and to serve as an index. The point at which the mercury stands when the tube is placed in melting ice, gives the volume of

the air at zero, when the ratio between the volume of the tube included between any two divisions and the volume of the bulb is known.

The instrument is now introduced into a box filled with water heated to a temperature t (*pl.* 19, *fig.* 14), so that the tube with the index may project above the side of the box. The index will then be driven to a certain point, and the increase of volume for the temperature t may be determined. In this manner the coefficient of expansion for dry gases is found to be 0.375, which Rudberg, by means of another apparatus, corrected to 0.365. This coefficient of expansion increases with increasing pressure.

In referring previously to the specific gravity of bodies, the temperature was left out of account. This could very well be done, as the slight differences of temperature usually occurring during such determinations, exercise little influence on the density of solids and liquids. The case is, however, very different with regard to gases, where the least change of temperature produces a material difference in the density. In investigations of the density of gases, a hollow ball is employed, provided with an arrangement by means of which it can be screwed on the plate of an air pump, there to be exhausted. A tightly-fitting stop-cock prevents the entrance of air when the ball is removed. The exact capacity of the ball must be known, which is best obtained by filling it with distilled water and then weighing it. The ball is then emptied, dry air admitted and weighed, and then again weighed after exhaustion of the air. If the experiment be performed with a perfectly exhausted ball, at a barometric pressure of 29 inches, and at a temperature of 0°C., or the results corrected to these conditions, the density of dry air, or its specific gravity, will be found to be 0.001299. Any other gas may be substituted for atmospheric air, and its density ascertained in the same manner. For this purpose, the *Pneumatic apparatus* figured in *pl.* 19, *fig.* 15, may be employed. This consists of a receiver, *c*, provided with a cock, *d*. This receiver is placed in a trough filled with mercury, a hand air-pump screwed on at *d*, and by the exhausting of the air, filled with the mercury. When entirely filled with the mercury, the cock is closed, and the air-pump replaced by the exhausted ball, *y*. The gas, as generated, is admitted through the tubes *a* and *b* into the receiver, and thence, opening the stop-cocks *d* and *e*, into the ball.

b. Effects of Heat in Changing the State of Aggregation of Bodies.

The state of aggregation of a body depends entirely upon heat, that is, whether it is to be solid, liquid, or gaseous. By heat many solids become liquid, and liquids gaseous; and conversely, by withdrawal of heat, gases may be changed into liquids, and these into solids. Sometimes the same body can be made to assume all three states in succession. Even if, in the case of certain bodies, this process has not been observed, we are fairly entitled to conclude that it is owing to the difficulty of attaining the extremes of temperature necessary for the purpose. It is thus certain that upon heat it depends whether a body shall be solid, liquid, or gaseous,

although some bodies before fusion experience chemical changes. The melting point of a body, or the temperature at which it becomes liquid, is invariable for one and the same body; as also, with certain restrictions, is the boiling point, or the temperature at which a liquid begins to vaporize. During liquefaction the temperature does not alter, however great a degree of heat may be applied; the excess of heat, therefore, becomes latent.

The opposite to melting in a body is its solidification, or the transition of a body from the liquid to the solid state. This generally takes place at the same temperature of a body as melting, all the combined heat being given out. We may be convinced of this by causing water to boil in a glass tube, and, when this is filled with steam, melting it together at the open end. If, now, the tube be cooled to about 15°F., the water will remain liquid; at the least agitation, however, it will become converted into ice, and a thermometer placed on the tube will ascend immediately from 15°F. to 32° F. As much heat, formerly latent in the water, will therefore be set free as sufficed to elevate its temperature 17° F.

The solidification of bodies takes place in different forms, according to the circumstances. If it be carried on slowly, a crystallization characteristic of each body takes place; if the cooling or solidification be accelerated, the particles have not time to arrange themselves properly, and irregular, confused formations are produced.

c. The Formation of Vapor.

If a fluid be in contact with the air, its amount gradually decreases by evaporation, or its conversion into vapor. The Torricellian vacuum is best adapted for exhibiting the laws of vaporization. In a broad vessel, VV′ (*pl.* 19, *fig.* 17), place three barometer tubes close to each other, the height of the mercury being the same in all. If some water be introduced into one of these tubes, as *b*, it will rise to the top, and the mercury will be sensibly depressed. This can only be produced by the giving off of a vapor which exerts an expansive force like the gases. The depression of the mercury gives the measure of the tension of the vapor. If some other fluid, as sulphuric ether, be introduced into the third tube, *b″*, there will be observed a much greater depression of the mercury, owing to the tension of ether vapor being much greater at the same temperature than that of water.

The elasticity or tension of vapor is increased by compression, just like air; there is, however, a certain limit or maximum of compression, above which the vapor becomes converted into a liquid. This maximum varies with the temperature, increasing with its increase. In this circumstance is a characteristic difference between vapors and gases. Suppose, in the apparatus, *fig.* 23, the upper barometer tube be filled for a few inches with mercury from which all air has been removed by boiling, and the rest with ether; now let the tube be inverted and immersed in the vessel *cn*, and the

ether will immediately rise to the top, there becoming partly converted into vapor. The mercury will by this means be depressed, the depression being produced by the tension of the ether vapor, and being in all cases greater than what would prevail in the presence of a vacuum above the mercury. If the tube be depressed still more in the mercury of the lower tube, the height of the mercury will remain unchanged, while if air were present it would increase, owing to its continued compression of the gas. The more the tube is depressed, the more the quantity of fluid ether increases, and the vapor is consequently condensed, not compressed; and this may be continued so far as to exhibit an entire condensation of the vapor, provided that no air be present. If the pressure be diminished by elevating the tube, the vapor will again be formed.

If vapor be contained in any space unequally heated in different places, the tension of the vapor in the whole space will be the same as in the coldest part, as may be shown by means of the apparatus represented in *fig.* 18. Let the bulb, *a*, be half filled with ether, and this brought to boil; after ebullition has continued long enough to drive all the air out of the bulb and the tube connected with it, quickly immerse the lower open end of the tube, *b*, in a vessel, *c*, filled with mercury. On cooling the bulb a part of the vapor will become liquid, and the mercury will ascend in the tube, until the bulb has attained the temperature of the surrounding air. If the bulb be cooled to a still lower point, the mercury will rise higher, and, in fact, to such a point, as if not only the bulb, but even the entire tube had been greatly cooled.

Various forms of apparatus have been employed to determine the expansive force of the vapor of water. This, however, at elevated temperatures and tensions, becomes very difficult. For moderate tensions, as those under 212° F., a form of apparatus may be employed, consisting of a vessel of mercury, in which are two glass tubes, the longer of which is a complete barometer, while in the shorter there is contained some water above the mercury, which is vaporized in the vacuum. The whole apparatus may be dipped in a vessel of water, and the latter heated, by degrees, from 32° F. to 212° F. Both barometers will have the same temperature, and the elasticity of the watery vapor thus formed, may be obtained for any degree of temperature, from the ratio of depression in the vapor barometer, to the height of the mercurial column in the complete barometer. When this depression is reduced to 0° we have the true tension of the vapor.

It is much more difficult to obtain the tension when the pressure exceeds several atmospheres. Quite recently, Arago and Dulong have instituted an extensive series of experiments, to obtain the elasticity of vapor at the highest pressures likely to occur. For this purpose they employed the apparatus represented in *pl.* 19, *fig.* 19, where *c* is a strong steam-boiler of plate iron, in which the steam is generated; *f*, the furnace; *y*, the grate; *t*, the tube through which the steam escapes. In the cover two gun barrels, *e* and *r*, are let in, open above and closed below, both being filled with mercury. The one descends below the water in the boiler, the other

does not reach its surface, so that the former has the same temperature as the water, the latter as the steam. A thermometer is sunk in each barrel, with its upper end bent horizontally; this horizontal portion, as represented more clearly in *fig.* 20, is maintained at a constant temperature by a stream of water. From the boiler rises a vertical tube, *b*, in which the steam ascends, and at *u* presses against the top of a column of water which fills the tube *udb*, and the upper part of the cast iron vessel, *vv'*. This pressure of the vapor is transmitted to the surface of the mercury in *vv'*, and produces a compression of the air in the manometer tube, *mm'*, by means of which the tension of the vapor may be ascertained. To determine the varying height of the mercury in the vessel, *vv'*, a glass tube, *nn'*, is employed, communicating with both the upper and under part of the vessel; in this tube the height of the mercury may be ascertained by means of a movable slide in the graduated rod, *z*.

Observations with this apparatus are conducted in the following manner:— Water is poured into the boiler, until the gun barrel containing the smaller thermometer stands just above the surface. This is kept boiling for fifteen or twenty minutes, with the safety-valve and the vertical tube, *b*, remaining open, in order to expel all the atmospheric air. When this is effected, fuel is placed in the grate of the furnace, and all the openings in the boiler closed. Both thermometers, and the mercury in the manometers, then quickly rise to a maximum, which being attained, the height of the mercury in the above-named instrument is ascertained by two observers, and carefully noted down.

To determine from experiments already made, degrees of tension which have not been observed, or in other words, to interpolate the series, it becomes necessary to develope certain empirical formulæ for the purpose, whose results shall agree in the closest possible manner with the observations already made. In these formulæ the force of tension, E, and the corresponding temperature, T, must occur, of which one or the other must be known. Such a formula, with which the observations made by Arago and Dulong agree closely, is that of Tredgold, available to a pressure of four atmospheres, where $\log. E = \frac{23.94571T}{800 + 3T} 2.2960383$. For higher tensions, even up to fifty atmospheres, we have the formula $E = (1 + 0.7153T)^5$ where T indicates the temperature above 212° F.

Hitherto investigations have been instituted principally with reference to the degree of elasticity of the vapor of water; quite recently, however, experiments have been made with the vapors of alcohol, sulphuret of carbon, and sulphuric ether, by Ure, Schmidt, and Muncke. Bunsen has investigated the tension of some condensed gases, particularly of sulphurous acid, cyanogen, and ammonia.

The *density of watery vapor* is best ascertained by means of the apparatus invented by Gay Lussac (*pl.* 19, *fig.* 21). Upon the furnace, *f*, stands the cast iron vessel, *c*, containing mercury; in this a graduated tube, *g*, is

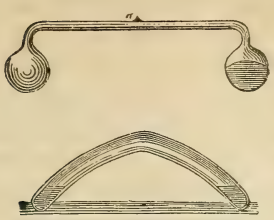
placed, about a foot in length, surrounded by the glass covering *m*, itself filled with an appropriate fluid. Upon the horizontal ground edge of the vessel, *c*, lies a small board, *t*, through which passes the divided vertical rod, *r*. Before introducing the tube, *g*, into the vessel, it must be entirely filled with mercury, so that after immersion it may remain filled with mercury, and contain no air-bubbles. Now introduce a small glass bulb, filled with water, and with the opening melted together, into the tube, *g ;* it will rise to the top, and on the mercury being heated, will burst by the expansion of the water. Vapor of water will immediately form in the upper part of the tube, *g*, and the mercury in it will sink. When, by continued application of heat, all the water becomes vaporized, the weight of the vapor will be known, provided that the volume of water in the bulb had previously been ascertained. The volume of the water is ascertained by the divisions on the tube, *g ;* its temperature by the thermometer; and then its tension by the graduated rod, *r*. This latter is pushed down until its lower extremity touches the mercury in the vessel, *c ;* the slide, *v*, is brought to an equal height with the surface of the mercury in the tube, by which means the height of the latter is ascertained. This, deducted from the barometer pressure, gives the tension of the vapor.

From the now known weight of a given volume of steam, which at a known temperature exerts a known pressure, the weight of any volume of vapor can be ascertained. As we have previously ascertained the density of the air to be = 0.001299, we can ascertain the weight of equal volumes of air and watery vapor at equal temperatures and equal pressures, and thus determine the ratio of density of the two. According to Gay Lussac, the density of steam is five eighths of that of the air. To determine the density, *d*, for other temperatures than those investigated, the following formula by Gay Lussac may be employed : $d' = d\frac{P}{760}\frac{(1+100\,\alpha)}{(1+\alpha T)}$, where *d* is the density at 212°F., and a barometric pressure of 29 inches ; P, the pressure, and α, the coefficient of expansion, amounting, according to Gay Lussac, to 0.00375. It is, however, assumed that vapors, like gases, follow the law of Marriotte to the maximum of tension.

The density of the vapors of various other liquids has been investigated by Dumas, Gay Lussac, and others.

Vapors are condensed by pressure and by cold ; nevertheless a vapor can be compressed without being at the same time partly condensed, only when it is not saturated. Hence we are led to the conclusion that even the so-called permanent gases are really vapors which are far from their point of saturation. Davy, and particularly Faraday, have succeeded by means of great cold and pressure in condensing into liquids, and even solids, gases which had previously been considered permanent. The method employed consisted in condensing the gases by their own pressure, for which purpose an instrument was used similar in its principle to Wollaston's cryophorus for producing artificial ice, but rather more simple.

Wollaston's Cryophorus.



Faraday's Condensation Tube.

In the one side of the tube are placed the materials from which the gas is to be generated, as, for instance, cyanide of mercury, &c.; and this part being carefully heated over a spirit lamp, the gas will pass over into the other side of the tube, and there be compressed more and more, by the arrival of successive portions, until condensation ensues by placing the extremity in a freezing mixture.

d. Mixture of Vapor with Air.

When vapors and gases, or aeriform bodies in general, exercising no chemical influence upon one another, become mixed together, they do not, like liquids, separate according to their specific gravities, but each gas diffuses itself uniformly throughout the entire space, just as if the others were not present. If this were not the case, the watery vapor from streams, &c., would, on account of its lightness, speedily become elevated above the atmosphere, until, finally, all the water on the earth's surface would become converted into vapor and disappear from it. The coexistence of two gases may be readily exhibited by producing a communication between two glass vessels, as in *pl.* 19, *fig.* 22, the one containing hydrogen, and the other carbonic acid gas. The tension of the mixture, which is diffused uniformly through the whole space, is in every case equal to the sum of the tension of the individual gases, each one being supposed to fill the entire space exclusively.

That vapors resemble gases in this respect may be shown by the apparatus represented in *fig.* 23. Fill a barometer tube with mercury, allowing a small portion of the tube to remain free, and immerse it in the mercury of the vessel *cn*, upon which the air contained in the tube will expand, and occupy five times, for example, its original space. If some sulphuric ether be introduced in the manner previously explained, the mercurial column will sink still deeper; by depressing the tube, however, the space above the mercury may be brought to the same amount as before the introduction of the ether. Since the air is diffused through the same space as before, and this space contains as much vapor of ether as if no air were present, it follows that the tension of the mixture must be equal to the sum of the tensions of the air previously present, and the saturated vapor of ether for the existing temperature. This is completely verified by examining the height of the mercury above the level in *cn*.

The conversion of liquids into vapors or gases is called vaporization; it

takes place either by boiling, in which case vapor is formed throughout the whole mass of the liquid, or by evaporation, where the surface only is affected. In the first case, two conditions must be fulfilled: firstly, the heat must be sufficient to enable the tension of the vapor to resist the pressure of the liquid on the vesicles of vapor, on which account the boiling point depends upon the amount of this pressure; secondly, there must be enough heat to admit of a sufficiency being absorbed in the formation of steam. For this reason the rapidity of boiling will depend upon the amount of heat applied within a given time. Under the receiver of the air-pump, water of moderate warmth, as at 86° F., will begin to boil as soon as the air is sufficiently rarefied.

A curious experiment, relating to this subject, may be performed by means of the apparatus represented in *fig.* 24. A glass balloon, *a*, with a long neck, is half filled with water, and this is made to boil: when, by the ascending steam, all the air is expelled, the mouth is closed by a cock, *b*, and the balloon inverted as in the figure. Now, if cold water be poured on the upper part of the balloon, the water in this vessel will begin to boil violently, owing to the condensation of the vapor above the water, and the consequent diminution of pressure.

Since the height of the boiling point of any liquid depends upon the atmospheric pressure, the boiling will not only vary under different pressures at one and the same point, but the boiling point itself will be different in different countries, and at different heights above the level of the sea. Boiling water will therefore not be equally hot everywhere, as at Quito water boils at 194° F., while in the latitude and level of New York, 212° F. are required.

As by diminishing the pressure, the boiling of a liquid may be accelerated, so, also, by increasing this pressure, it may be retarded. *Papin's digester* (*pl.* 19, *fig.* 25) depends upon this principle, and is an instrument in which water may be heated far above the usual boiling point without boiling. It consists of a cylindrical vessel, *abcd*, of metal—best of brass or copper—whose sides can sustain a very great pressure, and which, after being filled, may be closed by a cover, pressed down firmly by the screw passing through the bow, *m*. The single opening in the cover is closed by a safety-valve, which may be loaded so heavily as to require a very great pressure to elevate it. If this vessel be filled with water and strongly heated, the water cannot boil, on account of the pressure exerted by the vapor which forms, and is prevented from escaping.

The lower layers of fluid, as is well known to our readers, have to sustain the pressure of all the superincumbent ones, in addition to the entire weight of the atmosphere; for this reason boiling should commence later at the bottom than at the top of the liquid. Nevertheless, the lower layers, expanded by heat, and becoming consequently specifically lighter, rise continually through those above them; the bubbles or vesicles of vapor which are formed, increase in size as they approach the surface, that is, as the pressure becomes less. This arrival at the surface takes place, however, only when the upper strata have attained the same temperature as the

lower; until this time the vesicles become condensed before they reach the top, giving out their latent heat to the upper strata.

Substances only mechanically united with water do not change the temperature at which boiling takes place; the case is different, however, if solution takes place, the boiling point being elevated. The steam formed is, nevertheless, pure watery vapor, and its temperature is precisely the same as if generated from pure water.

The generation of steam, both in respect to quantity and rapidity, depends entirely upon external circumstances, particularly upon the more or less suitable application of fuel, upon the material and form of the boiler, and upon the amount of surface coming in contact with the flame.

As boiling is a formation of vapor, taking place throughout the entire liquid, so there is still another formation of vapor, which takes place only at the surface, namely, exhalation or evaporation. This phenomenon occurs over the whole surface of the earth at all temperatures. The vapor thus formed has a certain tension, which, however, is not sufficient to overcome the pressure of the atmosphere. A chemical mixture here takes place, as between two gases, and the principal condition is, that the air be not saturated with vapor, else the exhalation ceases. For this reason evaporation does not take place so readily in a calm as during windy weather. As to the rest, evaporation is constantly in proportion to the amount of surface exposed to the air. In the section devoted to meteorology, we shall have occasion to refer more particularly to this phenomenon, and its influence in organic nature.

When a liquid evaporates, heat combines with the vapor, or becomes latent, as is shown by the fact, that whatever be the amount of heat applied, the temperature of the water never rises above the boiling point. The vapor must therefore take up the heat, even although its own temperature does not rise above the boiling point. This phenomenon may be illustrated by pouring upon the hand a few drops of ether or other quickly vaporizing liquid. A sensation of cold will be experienced, which is owing to the abstraction of heat from the hand during the production of vapor, this heat becoming latent in the vapor. The amount of heat latent in the vapor may be ascertained by allowing the vapor of a known amount of water to pass into a quantity of water, also known, and determining the temperature to which this water is elevated. Now, knowing how many units of heat, that is, how many times the temperature necessary to raise one pound of water, one degree in temperature, are required to raise the water to as many degrees as has been done by the steam, we can calculate the amount of heat which was rendered latent.

In the process of *distillation*, the steam raised from the liquid is conducted through a tube lying in cold water, and there condensed by becoming cooled. The heat given out in this process elevates the temperature of the circumambient water very considerably. The small apparatus of distillation (*pl.* 19, *fig.* 47) exhibits this very clearly. The steam generated in the small balloon passes through the straight tube into the wide one, provided with a funnel and an escape tube. The water poured in through

the funnel, enters the tube cold, and passes from it heated. In the larger cooling vessels, as in *fig.* 48 (exhibiting a sectional view), the steam-tube is carried in a spiral through the vessel, in order that the steam may remain as long as possible in contact with the cooling water, and become completely condensed. The upper strata of water become very soon heated, and if the process is to be continued any considerable length of time, must be renewed. This is done best by allowing the cold water to enter below, and as heated, to pass out above through an escape-pipe.

In reality, any cooler might be employed as a means of measuring the amount of latent heat, provided that it were known how much moisture was condensed in a certain time, and how much was given off into the cooling water. Brix, however, has invented a special apparatus for the purpose, represented by *fig.* 49. The cylindrical vessel, C, of about three inches in breadth and height, served as the cooler, and the steam generated in the retort, R, entered, not into a cooling tub, but into the cylinder, EG, which had an aperture in the middle, also cylindrical. The steam entered at M, while the inside of the condenser was in communication with the open air, by the tube, L, so that the air in the condenser could escape. The cooler, C, was filled with a given weight of water, whose temperature could be ascertained by a thermometer attached to the apparatus. In the space between the vessel, EG, and the cylinder, C, was placed a metallic disk, B, which could be moved up and down by means of a wire, so as to keep the water in constant agitation, and thus maintain it at an uniform temperature. The condensing apparatus was protected from the heat radiant from the heating apparatus and the retort. The liquid passed over was determined by the quantity remaining in the retort. Brix, in this manner, found the latent heat of watery vapor to be 540 units; that of alcohol in vapor, 214 units; of the vapor of sulphuric ether, to be 90 units, &c. From this it followed, in connexion with other experiments, that the latent heat of the vapor of different liquids is nearly in the inverse ratio of the densities of these vapors.

If a liquid boils in the open air, it retains the same temperature, owing to its continually receiving from the walls of the vessel heat enough to replace that rendered latent in the formation of vapor. The case is different, however, when ebullition takes place under the receiver of the air-pump: here the temperature continually sinks, as the latent heat derived from the water itself cannot be renewed. If we place under a shallow receiver on the air-pump, a small flat metallic capsule containing water, above a dish filled with sulphuric acid, and exhaust the air, the water will undergo a rapid evaporation, which is immediately absorbed by the acid. The rapid abstraction of heat from the water during the evaporation, will reduce its temperature to such an extent as finally to cause it to freeze. In Wollaston's cryophorus (see p. 269) [Physics, 95], water is likewise caused to freeze by its own vaporization. A small quantity of water is introduced into one of the bulbs aad brought to boil. When the other bulb and the tube are filled with steam, a small aperture left open is closed by melting the glass over it. If, now, all the water be collected in one bulb, and the other be immersed in a freezing mixture,

the vapor arising from the water will be condensed so rapidly as quickly to convert the water into ice.

e. The Steam-Engine.

The steam-engine serves in general to convert the vapor of water into a motive power. As early as the year 1687 Papin constructed an apparatus, which may be considered the earliest steam-engine on record. It is represented on *pl.* 19, *fig.* 26. It consists of a glass tube with a bulb blown at one end containing some water. A piston, *p*, moves air-tight up and down the tube. If while the piston is depressed the bulb be heated, the steam will force it up to the top; then, if dipped in cold water, the steam will become condensed, and a vacuum being produced, the piston will be depressed by the incumbent pressure of the atmosphere. Papin employed an iron cylinder instead of a glass tube. Savery made the first practical application of the steam-engine: he employed it in removing water from the bottom of mines; which was also the application of Newcomen's atmospheric engine. This latter was constructed according to the principles of Papin's engine, except that he admitted cold water into the cylinder to condense the steam. Watt made the great improvement of attaching a receiver, separate from the cylinder, to condense the steam. To him we also owe a great number of other important improvements; and with justice he is considered as the inventor of the steam-engine in its present perfected form.

A sectional view of Watt's steam-engine is exhibited in *pl.* 19, *fig.* 27. Here A is the cylinder, air-tight below and above, in which the piston, C, moves. The steam, generated in a boiler, enters through a pipe, Z, and thus is introduced into the cylinder alternately at the upper and lower ends at E and O. If it enter above, as in the figure, the steam beneath the piston escapes at O, and enters the condenser, I, through the pipe H, where it is condensed. There is thus a rarefied space beneath the piston, which must consequently descend when pressed on by the steam above. The condenser, I, stands in a cistern partly filled with cold water; there is a pump, K, to remove the water from the condenser, and likewise the air which rapidly accumulates there. This is called the air-pump. It brings the water from the condenser into the receiver, R, whence it flows through the pipe S to be partly employed in feeding the boiler. The water required for the boiler is brought through the pipe M to a pump, and, by means of this, through the pipe M′ to the boiler. This latter pump, called the hot water pump, like the air-pump, is kept in motion by the engine itself; thus, the pump rod, L, is attached towards one end of the great beam or lever set in motion by the piston, C, and is elevated or depressed with the elevation or depression of this end of the beam. During elevation the suction valve opens, and during depression the valve *n*. On the other side of the beam, not visible in the figure, is a pump rod, by which cold water is raised in the pipe T′, and brought through the tube U into the cistern in which is placed the condenser.

By means of the piston rod an alternating upward and downward motion

is communicated to one end of the beam, and of course an opposite motion to the other end. This upward and downward or rectilineal motion is converted into a circular by the connecting rod P, and the winch Q; the axis of this winch is the principal axis of the machinery to be set in motion. About it turns also the great fly-wheel, X, which serves to maintain uniformity in the motion of the engine. This, however, is not quite sufficient. A continual diminution of the resistance to be overcome by the engine, with the same head of steam, must gradually produce an increasing, and finally exceedingly dangerous acceleration in the velocity of rotation of the fly. To set a certain limit of safety to the velocity of rotation, it becomes necessary to attach a valve to the steam-pipe, Z, whose increase or diminution of the aperture may restrain to a greater or less extent the admission of steam to the cylinder. The turning of this valve is effected by the engine itself, by means of an apparatus termed the regulator or governor. An endless string, *i*, is passed round the axis of the fly-wheel, and a vertical pulley, so that the motion of the former is communicated to the latter. To the axis of the pulley a conical or bevel-edged wheel is attached, whose teeth play in those of a similar conical wheel placed horizontally. The axis of the latter is prolonged into a rod, whose upper end carries the conical pendulum (or centrifugal regulator) V. The pendulum consists of two heavy balls, which are attached to the upper end of the vertical rod, hanging by two short rods, which are again connected by means of other rods with a collar, *h*, surrounding the vertical rod. If, now, this rod rotate rapidly, the two balls separate in consequence of the centrifugal force; by this separation the collar *h* is elevated, and with it the connected angular lever, *r*S*a*, turning about the axis, S. This motion draws the horizontal rod *ab* towards the right, which turns the angular lever, *bcd*, about the axis *c*, and this lever, being connected with the vertical rod *ed*, draws it downwards. Now, as *e* is the extreme end of a lever arm, by whose turning the valve in the pipe Z is turned, this valve will be closed during the depression of the rod *de*. Less steam enters, therefore, than before, and the rate of the engine is retarded. The converse takes place when the engine goes too slowly: the balls fall, and by means of the connecting lever work, open the throttle valve for an additional supply of steam. This system of levers is in our figure represented only by lines as, being placed on the front side of the engine, it is not really visible in a section.

The alternate admission of the steam into the upper and lower parts of the cylinder, may be effected in various ways, among which the *cross-cock* (*pl.* 19, 2 *figs.* 29), is perhaps the simplest. This is a cock with two perforations: the tube, K, leads to the boiler, C to the condenser, O to the upper and U to the lower part of the cylinder. When the cock has the position of the upper figure, the steam enters from the boiler into the upper part of the cylinder, and at the same time escapes from the lower part to the condenser. When the piston reaches the bottom of the cylinder, the cock is brought into the position of the lower figure by a quarter turn, by which means the steam can enter the lower part of the cylinder, and escape from the upper.

More frequently, however, a *sliding-valve* is made use of for this purpose, as in our representation (*fig.* 27); it is delineated on a larger scale in *figs.* 30 and 31. The steam from the boiler enters through the pipe Z, into a space separated into two parts by a slide, and communicating by the pipes, D and E, with the cylinder. The middle space, *m*, into which the steam enters from the pipe Z, is entirely shut off from the upper part, *d*, and the lower, *a*: the two latter are in communication with the condenser as well as with each other by means of the cavity under the slide. If now the latter have the position represented in *fig.* 30, the steam will enter from *m* through D into the lower part of the cylinder, and the steam above the piston is drawn out through E towards *d*, through the slide towards *a*, and finally into the condenser. In the other position (*fig.* 31) the steam enters from *m* into the upper part of the cylinder through E, and the steam under the piston flows through D to *a*, thence to the condenser. *Pl.* 19, *fig.* 32, exhibits the slide-valve as seen in the direction of Z.

In all cases the arrangement for admitting steam into the upper and lower part of the cylinder, must be kept in operation by the engine itself, whether a slide-valve or a cross-cock be employed. This is done by means of the *governor*, the most important part of which is the excentric circular disk represented at *y* in *fig.* 27. This is attached to the axis of the fly-wheel, the centre of the disk not coinciding, however, with the centre of the axis (*figs.* 33 and 34). About the periphery of the disk is laid a ring, prolonged on one side into a rod, whose end fits at T into the arm of a lever working about a fixed axis. As the central point of the excentric disk is always at an equal distance from the point T, then, during a half revolution of the principal axis, the lever arm at T must pass from the position in *fig.* 33 to that in *fig.* 34, and back again when the revolution is completed. Thus the point T describes an arc, whose chord is equal to the diameter of the circle described by the central point of the excentric disk (during each rotation of the principal axis). As shown by *fig.* 32, the fixed axis, F, of the lever arm passes through the whole breadth of the machine. To this axis are attached two perfectly equal and parallel lever arms, N, on either side of the receiver, containing the slide-valve. *Fig.* 32 represents these foreshortened; *figs.* 33 and 34 exhibit only one of them, but in its true shape. A vertical rod, M, is attached to each of these lever arms; these rods being connected above by a horizontal cross-head bar, Q, to the middle of which is attached the rod R; to the latter the slide-valve is fastened. It is evident that the motion of the lever arms, N, must produce a rise and fall of the cross-head, Q, by means of the rods, M, and thereby elevate and depress the valves themselves.

Other applications of the steam-engine are to steamboats and locomotives. As, however, the principle is the same in all, being only modified for the special purpose, it is unnecessary to consider them here, especially as we shall have occasion to describe them minutely in another part of our work.

f. Specific Heat of Bodies.

One substance, when compared with another, has a greater or less capacity for heat, according as a greater or less amount of heat is necessary to produce a given change of temperature in it; the amount of heat thus necessary is called the *specific heat* of bodies. In some substances the capacity for heat varies. Thus, for instance, it requires more heat to elevate the temperature of platinum from 212° to 213° F., than to elevate it from 32° to 33° F. As, however, the capacity for heat possessed by water is constant, this is taken as the unit for all determinations. To determine the specific heat of a body, the following three different methods may be employed:—

1. *The method of melting of ice*, in which the calorimeter of Lavoisier and Laplace (*fig.* 43) is employed. The instrument, represented in section, consists of three vessels of sheet iron, one inside of the other. The interval, *a*, between the outer and middle vessels is filled with pieces of ice (not pounded finely), as also is the interval, *b*, between the middle and inner one; the water formed in melting flows off through the cocks *d* and *e*. If the body to be investigated be brought into the inner vessel, it becomes cooled to 32° F., the heat given off serving to melt the ice in *b*. The specific heat of the body is estimated from the mass and original temperature of the body placed in *c*, and the amount of ice melted. The ice or snow in the external space, *a*, serves only to keep off the surrounding heat.

2. The *method of mixtures* consists in heating a given weight of the body to be examined to a certain temperature, and then immersing it in water, whose temperature is elevated by the cooling of the body; from the quantity of the water, and the elevation of temperature produced in it, the specific heat of the body may be ascertained.

3. *Method of cooling.* A body cools, other circumstances being equal, the slower as its specific heat is greater. On this principle Dulong and Petit determined the specific heat of many bodies by means of the apparatus represented on *pl.* 19, *fig.* 44. Here *a* is a leaden receiver which may be exhausted of air; in the middle of its cover is a metallic nut, *c*, in which the thermometer, *d*, is fixed; the cylindrical mercury vessel of the latter is placed in a small silver vessel, *e* (shown in the figure between *figs.* 27 and 37), which is suspended by strings, and contains the substance to be examined. If the latter be a solid body it is reduced to powder and tightly pressed in the silver vessel. This, with the body inclosed, is now heated from 15° to 20° C., and introduced into the leaden receiver, *a*, which itself is immersed in a water-bath of given temperature. The receiver, *a*, is now exhausted of air, and observation made of the length of time necessary for the thermometer to fall 50° from a temperature exceeding that of the water by 10° C. From this interval of time, and the amount of the body, its capacity for heat may be ascertained. This method, however, gives no very trustworthy results.

From the experiments upon the specific heat of bodies, many remarkable results have been ascertained, among which not the least important is the law discovered by Dulong and Petit, that the specific heat of bodies is inversely as their atomic weights, or in other words, that the product of the specific heat and the atomic weight of certain bodies is always a constant quantity. There may be here and there slight differences, yet the products fall within narrow limits, being for elementary bodies between 37.849 and 42.703. The specific heat of a body experiences some change with its density. With respect to the specific heat of compound bodies, Avogadro, Neumann, and Regnault have determined, that in all such bodies of equal atomic and similar chemical composition, the above law equally holds good.

The specific heat of gases has been investigated by De la Roche and Berard. The apparatus used by them in their experiments is represented on *pl.* 19, *fig.* 46. The vessel, *a*, filled with air, has an air-tight cover, through which a perpendicular tube is raised, opening into a vessel, A, filled with water, so that the water can enter the vessel *a*. Through the air-tight cover of the vessel A, there passes into the water a tube open at both ends, so that when the water passes out of A, bubbles of air can enter A, through the lower end of the tube. From the vessel, *a*, pass two tubes, afterwards uniting into one, to the balloon, *c*. One of these tubes reaches nearly to the bottom of *a*, and is closed by a cock; through the other pass the upper portions of air from *a* to *c*. In *c* is suspended a bladder, *l*, filled with gas to be examined, from which the gas passes by the pressure of the air compressed in *c*, through the tube, *m*, into the worm of the calorimeter, *s*. It is previously heated in its passage through *e*, by the steam rising from boiling water. The gas, after passing through the calorimeter, is conducted through the tubes *n* and *p*, into the empty bladder, *e*, placed in the balloon, D. From this balloon there is conducted a tube, *q*, entering the vessel, *d* (filled with water), by two branches, one of which, provided with a cock, leads to the upper part of the vessel, the other goes nearly to the bottom. When the air passes through this latter arm from D to *d*, the water flows from *d* through a cock. If the bladder, *l*, be empty, and *c* filled with gas, then *a* must be filled with water, and *d* with air; all the cocks hitherto open are closed, and those closed opened. The air in D and *d* is immediately compressed by the water coming from B, and the gas driven out of the bladder, *e*, through the tubes *p* and *v*, towards the heating part, *e*, thence to the calorimeter, from whose worm it reaches the bladder, *l*, through the tubes *n*, *w*, and *m*; the air from *c* is forced into *a*, and the water in *a* flows out through the cock, *h*. If the bladder, *l*, be filled afresh with gas, the circuit begins anew. One thermometer indicates the temperature with which the gas enters the calorimeter, a second its temperature at the exit, and a third the temperature of the water in the calorimeter. A screen separates the calorimeter from the rest of the apparatus, to keep off accidental changes of temperature.

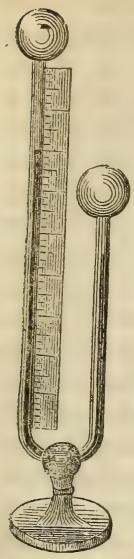
The heated gas passing through the worm of the calorimeter communicates to the surrounding water a certain amount of heat, so that

finally it assumes a constant temperature when it receives as much heat as it gives off. In this manner the excess of stationary temperature of the calorimeter above the surrounding medium may be determined for the various kinds of gases, and as in equal times equal volumes of gas pass through the apparatus, it is evident that the values of the specific heat of various gaseous bodies must, for equal quantities, be in direct proportion to the above-mentioned excess of temperature. Then taking the specific heat of air as unity, the proportional values for other gases may readily be determined. The philosophers above-mentioned, referred the specific heat of air, and consequently that of other gases, to water. As De la Roche and Berard have determined the capacity for heat of gases at a constant pressure, Laplace has determined the same for constant volumes.

g. Transmission of Heat.

Heat is transmitted partly by radiation, partly by conduction. Heated bodies send off heat on all sides, as it were heat rays, which traverse the air. If we imagine a source of heat at any point, then the intensity of heat at different points will be inversely as the squares of the distances. At a distance $=1$ the intensity $= 1 \times 1 = 1^2$; at a distance $= 2$ the intensity $= \frac{1}{2} \times \frac{1}{2} = (\frac{1}{2})^2 = \frac{1}{4}$, &c. In radiant heat, however, there is no uniform heating of the strata of the air, for although near a fire we may experience a piercing heat, this becomes immediately stopped on interposing a screen. Placing two large spherical or parabolic concave reflectors of polished brass (*pl.* 19, *fig.* 35) at a distance of sixteen or eighteen feet apart, and putting in the focus of one a piece of tinder, and in that of the other a red hot iron ball, the tinder will become inflamed. If, instead of the red hot ball, one merely hot, at a temperature of about 300° for instance, be employed, and instead of the tinder a thermometer, the latter will quickly rise. If a vessel containing hot water be placed in one focus, the ordinary thermometer will not exhibit any appreciable change of temperature; we are not to suppose from this, however, that the vessel of water radiates no heat. The truth of the matter is, that while a radiation does take place, the ordinary thermometers are not sufficiently sensitive to exhibit it, for which reason it becomes necessary to employ a more delicate instrument. Such thermometers are:

1. The *differential thermometer* of Rumford (*pl.* 19, *fig.* 36), consisting of two glass bulbs, *a* and *b*, connected by a bent glass tube. In this a drop of alcohol or sulphuric acid serves as an index, upon which the air presses from both sides. The position of this index or drop of fluid, when both bulbs are of the same temperature, is taken as the zero of the scale, which is placed on the horizontal part of the tube. If one bulb be heated more than the other, the drop, by the expansion of the contained air, will be driven towards the colder one; and the distance to which it is driven will be in proportion to the difference of temperature of the two bulbs.



2. The *differential thermometer* of Leslie (see accompanying figure) consists of a curved tube with bulbs blown at both ends, and standing on a foot. The tube is filled with a colored liquid. If the one bulb be placed in the focus of a concave mirror and the other out of it, at the least heating of the first bulb, the liquid in the tube will change its position; and the amount of this change may be read off on the scale.

3. *Melloni's thermo-multiplier* (*pl.* 19, *figs.* 37 and 37^a). This consists of a sensitive multiplier and a thermo-electric pile, composed of twenty-five to thirty fine needles or bars of antimony and bismuth, connected alternately at their extremities, and separated laterally by some non-conductor, the whole united into a compact bundle. Each of the terminating elements of the pile is connected with one of the projecting pins, which thus form the poles of the pile. The pile is lamp-blacked at both ends, and, with its covering, placed on a foot at *p*. The bonnets *a* and *b*, of which *b* is conical, serve to keep off from the pile all lateral radiations. In addition to this, *b* serves to concentrate the rays of heat coming from that side. The copper wire, twenty-two to twenty-four feet long, forming the galvanometer, is wound upon a metal frame. The carefully compensated magnetic needles are, as shown in *fig.* 37^b, united together and suspended by a fibre of raw silk, hanging in the middle of a glass bell. By turning the button *f*, the fibre with the needles may be slightly elevated or depressed. The extensible spiral wires, *g*, serve to connect the poles of the pile or battery with the extremities of the multiplier wire. The entire apparatus is so placed and adjusted upon a sufficiently firm table as that the thread shall hang in the middle of the graduated circle, and the needles point to the zero of the graduation. The least change of temperature between the two extremities of the pile produces an immediate deviation of the needle, which may be measured on the graduated circle.

If, in the focus of a mirror, any one of the above-mentioned pieces of apparatus be introduced, and in the other a body whose surface amounts to one third to three fourths of an inch, the apparatus will show that this body constantly radiates heat, even if its temperature be but little higher than that of the surrounding bodies. Thus, in a cold room, melting ice will radiate heat, and thereby elevate the temperature in the other focus. If the temperature of the room be above 32°, the thermometer in the focus of one mirror will sink if ice be placed in that of the other. This, however, is not an instance of radiation of cold, but simply an inversion of the usual operation; the thermometer is now the radiating body, giving off its heat to the ice. If Melloni's thermo-multiplier be employed, a mirror is not necessary, for by attaching the conical hood, *b*, the rays are concentrated by it so strongly, that even if the hand be held against the opening of the hood, at a distance of several steps, the radiation from the former will be sufficient to produce a very sensible deflection of the needle.

Heat rays, on striking any body, are either absorbed, reflected, or trans-

mitted. That an absorption of heat rays must occur is shown by the heating of a body placed in one focus of the above-mentioned system of concave reflection, whenever a heated body is placed in the other. Although this power of absorption is common to all bodies, it is yet not the same in all, the less dense the body the greater being its absorbing power. Of the reflecting power of bodies we have an illustration in the above-mentioned concave metallic reflector, the mirrors themselves experiencing no elevation of temperature when a heated body is placed in one of their foci. The powers of absorbing and reflecting heat in bodies may be considered as complementary to each other; both taken together explain what becomes of the heat reaching any body. Thus, a body reflects what it cannot absorb, and the greater the absorption the less the reflection, and vice versâ. The angle of reflection of heat rays is equal to the angle of incidence. From the surface of plates not well polished, rays are dispersed irregularly, or diffused in all directions; and the same is the case with heat rays. Of this we may readily become convinced by directing a small beam of light against the wall of a dark room. By presenting the thermo-electric pile towards the light spot, a deviation of the needle will be observed in whatever part of the room it may be placed; it returns immediately to 0, however, whenever the aperture admitting the beam of light is closed. There is of course no other heat present than that diffused by the beam of light.

Solid bodies may transmit heat rays just as transparent do light. These are called by Melloni *diathermanous*, and those which intercept heat, *athermanous*. Melloni, in his experiments on the passage of heat rays, employed the apparatus represented in *pl.* 19, *fig.* 37. As sources of heat he employed: 1. a Locatelli lamp; 2. a spiral of platinum wire kept red hot by the flame of alcohol; 3. a blackened copper plate, *l* (*fig.* 39), heated to 752°F. by an alcohol lamp; 4. a hollow cube of brass plate (*fig.* 40) filled with hot water, maintained at an equal temperature by a lamp. These sources of heat were successively placed upon the stand *e*. The screen, *o*, composed of two brass plates, and turning on a hinge, could be brought between the source of heat and the thermo-electric pile, to keep from the latter any heat rays. The plate of the body to be investigated was placed at *r*. If the source of heat be placed at such a distance that the needle experiences a certain deflection (30°), and a plate be interposed at *r*, it was found that the needle returns more or less to its original position; and also that plates of equal thickness and transparency do not transmit an equal number of heat rays, and even that some bodies transmit heat better than others of much greater transparency. The thickness of the plates employed averaged from one third to two thirds of a line. Plates of rock salt were found to be most diathermanous ($92\frac{0}{0}$), and plates of ice the least ($6\frac{0}{0}$).

It was also found that the difference of radiants involved a difference in the number of rays transmitted through the same plate. In the lamp of Locatelli the transmission was greatest, in the brass plate the least, although the original deflection (30°) was the same in all. Plates of rock salt

transmitted the heat of all equally well; plates of ice only that of the Locatelli lamp. For all other sources the power of transmitting was zero.

That heat rays are capable of refraction like those of light, may be shown by the apparatus represented in *pl.* 19, *fig.* 41. Upon a stand is placed a prism of rock salt, and at some distance the Locatelli lamp. The direction is now observed in which the rays of light emerge from the prism with the least deviation from their original direction, and the thermo-electric pile placed in it: the needle will become immediately deflected. The same will be the case if, for the Locatelli lamp, the platinum spiral, the cube of hot water, &c., be substituted. The deflection ceases immediately on slightly moving the pile, whence it follows that the rays from the different sources are refracted by the rock salt.

In this great difference in the transmitting power of diathermanous bodies the question suggests itself, whether in the athermanous bodies the power of absorption and diffusion be not different. Melloni has instituted the investigations necessary to answer this question. He cut out disks of equal diameter from the same copper plate, blackened them on one side, and coated them on the other with the substance whose power of absorption was to be ascertained. He then introduced the plates, one after the other, into the apparatus, so that the blackened side was directed towards the pile, and the coated side towards the source of heat. This side became heated by absorption, and this heat, being communicated to the opposite side, was brought to bear upon the pile. He thus discovered a great difference both in the absorbing power of the bodies themselves, as also in respect to the different sources of heat. Lamp-black exhibited the maximum power of absorption, only $13\frac{8}{9}$ of which was exhibited by a bright polished surface.

Melloni and Forbes have also indicated a polarization of heat rays, by processes similar to those by which the same change is produced in light.

Dulong and Petit have instituted the most accurate experiments upon the laws of *cooling* by means of the apparatus represented in *fig.* 42. Here *a* is a copper vessel filled with water kept at a uniform temperature; *b* is a balloon of copper plate, blackened internally and sunk in the water; it is sustained by the frame *c*. Upon the broad ground edge of the balloon is placed a level plate, *d*, of thick glass, and upon this (like a receiver on the plate of an air-pump) a broad glass tube, *e*. This is provided above with a cock, and is connected by a leaden tube, *g*, with an air-pump, of which the figure represents only the plate *h*. The tube *k* is filled with chloride of calcium, which serves to dry the gas coming from the gasometer *l*, in case experiments are to be made upon cooling in different gases. The bodies whose cooling is to be observed in this apparatus are large thermometers with spherical bulbs, fastened by a cock in the glass plate *d*, and capable of being raised with it. When such a thermometer has been heated to the proper temperature, it is quickly introduced into the balloon, the tube *e* placed over it, and the air pumped out. The depression of the mercury is to be observed with the assistance of a good watch.

It has been found by experiments with this apparatus that the rate of cooling is not uniform, that is, that bodies do not cool equally in each successive minute. The greater the excess of heat possessed by bodies above that of surrounding bodies, the more rapidly does cooling take place. The loss of heat of a body is, however, only proportional to the excess of temperature when the latter amounts to about 100°—115°F.

h. Conduction of Heat.

Heat passes from one body to another, not only by conduction, but also by immediate contact; all bodies do not possess, however, the same conducting power. Some bodies allow heat to pass with great facility from one particle to another; these are called *good conductors.* Others may be inflamed at one point, while in another quite near to it, the temperature may be but slightly increased. Such are *bad conductors.* Metals form the best conductors; spongy or very porous bodies the worst.

If several rods of different material, but of the same size, be coated at the upper end with wax, and set on a hot plate, the relative rapidity of melting which will be observed in the wax, will indicate the relative conducting power of the different materials.

If an elongated body, as a metallic rod, be connected at one end with a source of heat, this heat will gradually diffuse itself throughout the entire mass: it will, however, be greatest in the vicinity of the source, and decrease inversely as the square of the distance from it. In similar rods of different metals, the conducting power is as the square of that distance from the source of heat, at which, other things being equal, equal excesses of temperature have been observed.

In liquids and gases heat is diffused principally by currents. As the heated strata become specifically lighter, and therefore rise to the surface, the displaced strata occupy their place and become heated in turn. Liquids, and still more gases, are much poorer conductors than metals; hence it follows that porous bodies, powdered substances, and even metals in a state of minute division, conduct heat much worse than those which are dense, on account of the pores being constantly filled with air or other gases.

i. Sources of Heat.

The principal source of heat is the sun, and next to this, chemical combinations, combustion particularly, that is, the rapid combination of bodies with the oxygen of the air. The heat produced in such combustion is estimated by the degree to which equal quantities of the combustibles elevate the temperature of equal quantities of water. The most satisfactory experiments on this subject have been instituted by Rumford, Lavoisier, Laplace, and Despretz.

The animal heat is constantly different from that of the surrounding air; in the temperate and frigid regions it is generally warmer, in the tropical colder than the air. The animal body consequently possesses an independent heat which is continually renewed. The heat of the human body appears to be nearly the same in all parts of the body, and under the most diverse circumstances (cases of disease excepted), varies only from 96.5° to 102° F. The animal heat of birds is higher than that of any other animal, and that of insects perhaps lower. The source of animal heat is a peculiar combustion taking place in the body between the oxygen inspired through the lungs and the carbon of the body. Other causes there are, in all probability, but this is unquestionably the principal.

Heat may also be produced by mechanical means. Thus a very considerable elevation of temperature may be produced by the compression of air, as shown in the little apparatus for inflaming tinder, where the tinder fixed underneath an air-tight piston, is inflamed by the sudden depression of the piston and consequent compression of the air. Even in solid bodies a considerable compression, as in coining money, produces a sensible elevation of temperature. Finally, friction is the principal source of the mechanical production of heat, for the pivots of a wheel become heated to redness if the friction be not diminished by some anti-attritient. Wood also may be set on fire by rubbing two pieces together.

OPTICS; OR, THE THEORY OF LIGHT.

a. Propagation of Light.

Bodies are divided, with regard to light, into luminous and non-luminous, of which the former emit light peculiar to themselves, while the latter do not. Now, luminous bodies are again divided into transparent, or those which transmit light; and opake, or those which totally intercept its passage. Light is propagated in perfectly uniform media, in straight lines; and in curved when the medium is not of this character. In passing from one transparent medium to another, it experiences a deviation or break in its path; that is, the rays of light undergo refraction. This, for instance, is very evident in its passage from water into air. Take a vessel, *v* (*pl.* 21, *fig.* 1), and place in the bottom of it a piece of money. Assume such a position with regard to this vessel, that the money shall be just concealed by the edge, *b*, of the vessel. Fill this with water, and the coin will appear as if elevated, and in plain sight. It appears to lie at *n*, though its position is not changed in the slightest degree; the illusion is produced by the bending of the ray, *mio*, coming from the object to the eye at *o*. Upon this same principle is explained the fact, that the stars are visible before their real rising, and after they have actually set. See Astronomy, section 47.

Light is most intense at its source, and experiences a gradual diminution in its intensity as the distance from this source is increased, as is shown by the fact of a body becoming less illuminated as it recedes from any radiant. The law of this diminution is the same as in the case of heat; the intensity decreases as the square of the distance from the radiant. A body which experiences a certain intensity of light at a distance of one foot, will receive at the distance of two feet only one fourth of this amount, and at the distance of three feet one ninth, &c.

When light coming from a single luminous point strikes upon an opake body, there arises behind this, on the side opposite to the radiant, a dark space called a shadow, bounded by a conical surface. If the luminous body be of considerable extent, it becomes necessary to distinguish the full shadow, or that space receiving no light at all, from the half shadow, or the space receiving light from some parts of the luminous body and not from others. In *pl.* 21, *fig.* 2, let A be a large luminous sphere, and B a smaller opake one, then both the full and the half shadows will be conical spaces, only of opposite positions; for while the diameter of the full or central shadow diminishes with the distance from the luminous body, ending finally in a point at S, that of the half shadow increases more and more with this distance. *Fig.* 3 represents the appearance which would be presented by their shadows, if received at *m'n*, on a screen. It will be seen that the central shadow is smaller, and the half shadow larger, with the distance from the body producing the shadow, until the former vanishes entirely, and only the latter remains. This increases in size, but at the same time diminishes in intensity until it also disappears.

If the light from a luminous or illuminated body falls upon a screen with a small opening, the light passing through forms a well defined beam, producing upon a second screen a bright spot on a dark ground. If an aperture of this character be made in the window shutter of a perfectly dark room, an inverted image of external objects will be found upon the opposite wall (*fig.* 4). A beam of solar light under such circumstances presents a round image, even though the aperture be angular, as a circular image is formed by every point of the aperture, and the combination of these innumerable round images must necessarily give a single image that is round.

The velocity of light is extraordinarily great. It passes from the sun to the earth in eight minutes and thirty-six seconds, and in each second traverses not less than 192,000 miles. It has been a problem in Astronomy to determine this velocity by observations on the motions of Jupiter's satellites (see page 116). The calculations were first made by Olaus Römer and Cassini.

b. Reflection of Light.—Catoptrics.

When a ray of light strikes a very smooth level surface, a polished glass or metallic plate for instance, it is reflected, and the angle formed by

the incident ray with a perpendicular to the surface at the point of incidence, will be equal to the angle formed by the reflected ray with this same perpendicular. Thus, in *pl.* 21, *fig.* 5, suppose a ray to come in the direction *dl*, forming an angle, *dlp*, with the perpendicular *lp*, the reflected ray will be *lr*, making the angle $dlp = plr$. The former is called the *angle of incidence*, the latter the *angle of reflection*. Rays reflected in this manner are said to be regularly reflected. There are, in addition, rays that are irregularly reflected, or scattered in all directions from the radiant beam. The intensity of this scattered light is in proportion to the want of polish of the reflector.

To prove the preceding proposition respecting regularly reflected light, the following method may be employed. Take a vertical graduated circle, C, (an altitude circle) *fig.* 6, about whose axis a telescope, *l*, moves. Have also an artificial horizon of mercury or linseed oil, in a wooden vessel; then sight with the telescope, first at a star and then at its image reflected in the artificial horizon. On measuring the angles which the sight lines *oe* and *o'e* form with the horizontal line *cf*, it will be found that they are equal; whence, as *eo* is parallel to the incident ray *ci*, both coming from an infinitely distant star, it follows that the incident ray, *ci*, and the reflected ray, *io'*, make equal angles with the horizontal line, and consequently with the vertical or plumb line, *pi*. The three lines, *ci*, *io'*, and *pi*, evidently lie in one and the same plane, or the plane in which the telescope rotates.

A plane mirror shows the images of objects lying before it, which images must be symmetrical with the object, in relation to the reflecting plane. In *fig.* 7, let *m'm* be a plane mirror, and *l* a luminous point before it, which sends to the mirror the ray *li*. This is reflected in the direction *ic*, and produces an impression upon an eye at *c*, as if it had come from a point, *i*, in the direction *ic*, and behind the mirror, so that $il' = il$. An eye at *c'* will observe the point *l* in the same point *l'*. Draw *ll'* cutting *mm'* in *k*, *ll'* will evidently be perpendicular to *mm'*, and be bisected at *k*. We thus find the image of a luminous point in a plane mirror by letting fall from the luminous point a perpendicular to the mirror, or the mirror produced, and taking on this perpendicular, behind the mirror, a distance equal to that of the point in front of it. As this proposition holds good for every point of an object emitting light, the image of such an object may be readily constructed. Thus, in *fig.* 8, *ab* is the image, in the mirror VW, of the arrow AB, and it is evident that the image and object are perfectly symmetrical, with respect to the plane of the mirror. The construction lines, A*k* and *ka*, B*l* and *bl*, exhibit the position of the image, while the other lines show the correctness of the figure with reference to the reflection of the rays of light.

The intensity of the reflected light, whose direction may be ascertained in the most exact manner, depends on the one hand upon the medium in which the light moves and in which it falls, and on the other hand upon the angle of incidence: the more acute the angle the greater the number of rays reflected.

If two plane mirrors be placed together at any angle, an object between

them may exhibit many images. In *pl.* 21, *fig.* 9, let VW and ZW be two plane mirrors, at right angles to each other, with a luminous point placed between them. An eye at O sees, besides the point or object itself, its two images, *a*, *a'*, reflected from the two mirrors. But the rays reflected from one mirror are partly reflected back again by the other, on which account the images, *a*, *a'*, may themselves be considered as objects or radiant points: the two will form a third image in the same point, *a''*; more than these three images cannot exist at this angle. The number of images always depends upon the inclination of the mirrors; if this amount to 60°, there will be six images, including the object, &c.; and, in general, this number (including the object) will be represented by $\frac{360}{\alpha}$, where α is the angle of inclination of the two mirrors. The number therefore increases with a diminution of the angle; when this is zero, or the mirrors become parallel, this number becomes infinite.

Upon this principle depends the construction of the instrument invented by Brewster in 1817, and called by him the *Kaleidoscope* (*figs.* 105, 106). This consists of a cylindrical or conical tube with a cap at one end, in which is a hole to look through. In the tube two plane mirrors are fixed, so as to form with each other a certain angle, 60° for instance. Instead of the mirrors usually employed, glass plates blackened on the back may be used. A false bottom of glass is placed at a short distance from the extremity opposite to that in which the eye-hole is situated, and over the extreme end is fitted a second plate of glass by means of a cap. Pieces of colored glass, feathers, and other brightly colored objects are placed in the space between the two plates just mentioned. On looking through the eye-hole, towards the light, various hexagonal symmetrical images will be formed by the reflection of the objects in the mirrors, which will be changed by every change in the relative position of the objects. Other polygonal images besides the hexagonal will be formed by varying the inclination of the mirrors. It must not be forgotten, however, that by too frequent reflections the light is enfeebled, and part of the image will be very faint. The dodecagon should be the maximum, in which case the angle of inclination must be 30°. The kaleidoscope is of great use in drawing patterns for various fabrics, for which purpose it has been variously modified, so as to produce other figures than the rosette.

Wollaston's *reflecting Goniometer* depends for its principle upon the reflecting of a ray of light. A goniometer is any instrument used for measuring the angle formed by any two sides of a crystal, and may be of various constructions, some of which will be found elsewhere. With regard to the goniometer of Dr. Wollaston, let (*pl.* 21, *fig.* 10) *abcd* be the section of a crystal, *ab* and *ac* the surfaces, appearing here as lines whose angle is to be measured. If now the edge, *a* (projected into a point in the figure), be horizontal, an eye at *o* observes in the surface, *ab*, the image of a distant horizontal line, to which the edge, *a*, is parallel also as a horizontal line. Let the eye be held in such a manner that the image of

the line, a window-bar, for instance, be visible by reflection from the surface, *ab*, at a certain readily determined part of the floor; turn the crystal about an axis parallel to the edge *a*, or about this edge itself, until the same object is seen in the same place by reflection from the second surface, *ac;* this will be accomplished when the angle, *fac*, has been described, and the surface, *ac*, is in the same position formerly occupied by *ab*. The angle of rotation, *fac*, can be measured if the axis of rotation be the axis of a graduated altitude circle; subtract this from 180°, we shall have the angle required, *bac*. *Figs.* 11 and 12 represent a reflecting goniometer, the latter of which is a sectional view: *ab* is the section of the graduated circle; *i* that of the part containing the vernier. The disk of the circle turns about a graduated axis reaching to *ef*, turned by means of the milled wheel, *ef*, which carries in addition the disk, *cd*. For fixing the latter disk, as also the circle itself, the pressure screw, *l*, is employed, and for fine adjustments of the circle the screw *o*. The axis of the circle itself is hollow; in it, by means of the head, *gh*, turns another axis, *mn*, by whose rotation is turned the right-angled arm, *nqp:* to this is fastened a similar arm, *prs*, turning about *p*. If the circle be fixed by means of the screw, *l*, the axis, *mn*, can be turned separately; if *l* be loosened, then the axis turns with the circle. The crystal is fixed to the rod, *tu*, by a little wax, and the whole instrument so adjusted as that the plane of the circle shall be perpendicular to that of the window. To measure by means of the instrument, adjust the circle to the zero, fix it there by means of the screw, *l*, and arrange the crystal in such a manner that the edge of intersection of the two planes whose angle is to be measured, shall fall in the prolongation of the axis, *mn*, until the image of the window-bar appears at the given part of the floor. Then loosen the screw, *l*, and turn again until the image of the window-bar is seen at the same part of the floor from the second surface. The angular value of this rotation may then be read off.

For large and heavy crystals the *goniometer of Gambey* (*fig.* 13) is better suited: it may also be employed in measuring the angle of a prism. For this latter purpose the prism is so adjusted that the image of any distant object appears in the cross-hairs of the telescope. The prism is then turned about its vertical axis until the same image reflected from the second surface appears in the cross-hairs, upon which the angle by which the prism has been turned is to be read off.

The *reflecting Sextant* is a very important application of the reflection of light: its principle is illustrated by *fig.* 14. Here A is a small mirror whose upper half is not silvered, so that an eye at *o* can see through the uncovered portion of the glass plate. B is a second mirror, which may be turned about an axis perpendicular to the plane of the figure. When the mirrors are mutually parallel, the eye at *o* will see a distant object situated in the direction *o*A, directly through the uncoated half of the mirror, and its reflection in the other half, while the ray, *e*B, coming from the object and passing near the mirror, A, is reflected from B to A, and thence to *o*. If the mirror B be turned, an image, visible through the uncovered part of the mirror A, will not be seen in the silvered portion, but the image

visible will be that of an object from which the ray, *f*B, comes. The angle which the two sight-lines, B*e* and B*f*, from the two objects make with each other, is precisely twice the amount of the angle by which the planes of the two mirrors are now inclined to each other. It would be very easy to show that the angle *e*B*f* is twice as great as *g*B*h*. *Pl.* 21, *fig.* 15, represents a reflecting sextant of the simplest construction. For full particulars respecting this instrument in its various forms, as also for a more complete illustration of its theory, we must refer our readers to that part of our work where the sextant is treated of at length.—(Pp. 66 and 165.)

If a ray of light impinge upon any polished curved surface, it will be reflected as from a plane tangent to the surface at the point of incidence. A luminous point at the centre of a sphere emits rays which are all reflected back again to this centre. If the luminous point lie in one focus of an ellipsoid, its rays will be reflected to the other focus, and then back again by reflection to the first. If the luminous point be placed in the focus of a paraboloid, the rays will be reflected parallel to the axis: if a number of rays be incident parallel to the axis, they will be reflected to the focus. Spherical mirrors are either concave or convex. A spherical convex mirror is a part of a sphere polished externally; a spherical concave mirror is part of a sphere polished internally. The centre, *c* (*fig.* 77), of the sphere is called the centre of curvature; the line *ca*, connecting it with the centre of the mirror, is called the axis of the mirror; the angle *mcm'*, formed by lines drawn from the centre of curvature to exterior points diametrically opposite to each other, is called the aperture of the mirror. If a luminous point be placed at the centre of curvature, all its rays will be reflected back to it again. If the radiant be at a very great distance from the mirror, its rays striking the mirror may be considered as parallel to each other. Rays falling upon the mirror parallel to each other (*fig.* 16) are reflected to a common point, *c*, called the focus of parallel rays, situated half way between the centre of curvature and the centre of the mirror (*fig.* 17). This is strictly true, however, only of those rays which are very near and parallel to the axis: the more they are removed from the axis, the nearer to the mirror is the focus. The focus of parallel rays, striking the mirror at a distance of 60° from the axis, will lie in the centre of the mirror itself. If all the parallel rays impinging upon a mirror are to be reflected to the same point, its aperture must not amount to more than from 8° to 10°; in this case all the rays may be considered as central. If the luminous point be not at an infinite distance, but a point, *m*, of the axis itself (*fig.* 16), the focus will be nearer the centre of curvature than the centre of the mirror; if placed at the centre of curvature, the focus will be there also. If the radiant be placed between the focus of parallel central rays and the centre of curvature, the focus will be further from the mirror than this centre, and will recede more and more as the radiant approaches the centre of parallel rays. In this focus the radiant will emit rays which will be reflected in lines parallel to the axis and to each other, and there will be no convergence to a focus at all. If the radiant be between the focus of

parallel central rays and the mirror, the rays will be reflected diverging, as if they came from a point behind the mirror (*fig.* 18).

All that has just been said applies equally to rays reflected from points not in the axis, as an imaginary axis may be drawn through the centre of curvature and the radiant, provided the mirror be sufficiently large.

On the principles just enumerated, it becomes easy to determine the nature of images formed in concave mirrors. If an object, AB (*fig.* 19), be placed between the centre, C, and the focus F, the mirror exhibits an image, *ab*, inverted and magnified, and situated at a greater distance from the mirror. For an object at *ab* the image will be inverted, diminished, and nearer to the mirror. The further the object from the mirror, the nearer is the image to the focus of parallel rays; if this distance becomes infinite, as in the case of the sun or stars, the image will be in the focus. An object at the centre of curvature will have an image there also, and inverted. Objects at the focus, and between this and the mirror, will exhibit no image whatever in front.

The images formed in concave are very different from those of plane mirrors. The latter appear as if proceeding from a point behind the mirror, thus diverging, while the former converge. The images formed by a concave mirror may be thrown on a screen of white paper or ground glass.

The radius of curvature of a concave mirror may be readily determined by observing the place before the mirror at which the image of the sun is formed on a screen. This image will, of course, be in the focus of parallel rays, and twice the distance thus formed will be the radius of curvature.

Although no image is formed in front of a concave mirror by objects placed between the focus and the mirror, yet an apparent image will be formed behind it. If in *fig.* 20 AB be the object, the normal ray, A*n*, will be reflected back in the direction *n*AC. A*e*, however, which is parallel to the axis, will be reflected to F; *n*AC and *e*F, produced backwards, will intersect at *a*, where will be the image of A. Obtain *b*, the image of the other extremity, B, of the object, and *ab* will be the image required. It will be observed that this is larger than the object, lies behind the mirror, and is erect.

A *spherical convex mirror* (*fig.* 21) has no actual focus, as the reflected rays do not unite; they diverge, however, after reflection, as if they came from one and the same point behind the mirror. When the rays are parallel to the axis, this point, *v*, will be half way between the centre of curvature and the mirror, thus corresponding to the focus of parallel rays in the concave mirror. The focus of parallel rays in the convex mirror is called the *virtual or apparent*, to distinguish it from the *real or actual* focus of the concave mirror. A convex mirror exhibits a direct, but diminished image, *ab*, behind the mirror (*fig.* 22), of which we may become easily convinced, by comparing the explanation of *fig.* 20, and considering F as the focus.

When the rays proceeding from a luminous point, and reflected from a

curved surface, do not unite in a focus, a *caustic curve* is produced. This is formed by the intersection of two contiguous rays in the same plane. *Fig.* 23 exhibits a caustic curve produced by a curved reflecting strip.

c. Refraction of Light.—Dioptrics.

When a ray of light passes from one medium to another, it experiences a change of direction, or becomes broken, i. e. refracted. When the media are perfectly homogeneous, the refraction takes place suddenly; as, however, in most cases there is a stratification of media, this refraction, strictly speaking, takes place in a curve, as has been already referred to in Astronomy. This curvature is generally so slight as to be scarcely sensible, and but little error is involved by considering refraction to take place in straight lines. If, in *fig.* 24, the horizontal line passing through *i* separate two different media, as water and air, then the angle formed by the incident ray, *il*, with the vertical line, *ni*, is called the *angle of incidence.* The *angle of refraction* is that angle formed by the ray, *ir*, after entering the second medium with the same vertical line produced on the opposite side. The plane of incidence passes through the incident ray and the vertical; the plane of refraction through the same vertical and the refracted ray. Generally, the incident ray is refracted into but one line; there are cases, however, in which this ray becomes split into two, as will be seen when we come to the subject of polarization.

For simple or single refraction, to which we here restrict ourselves, the following laws present themselves:—1st. The plane of refraction coincides with the plane of incidence. 2d. For the same media, the sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction. Suppose in *pl.* 21, *fig.* 25, *l* to be a ray of light, incident at the same point as, and in the same plane with a vertical, *dd'*, and there to suffer a refraction. If it were desired to determine the angles of incidence and refraction on a graduated circle, we may suppose a circle to be described about the point of incidence, cutting the two rays. There *ad* would be the sine of the angle of incidence, and *cd* that of refraction. If the angle of incidence were found by direct measurement to be $= 15°$, then the angle of refraction would be $11° 15'$; if the former, again, were $60°$, the latter would be $40° 30'$; and the sines of these angles are respectively, 0.259, 0.194, 0.866, 0.649. Constructing the above proportions we have $\frac{\text{sin. } 15°}{\text{sin. } 11° 15'} = \frac{0.259}{0.194} = \frac{4}{3}$, and $\frac{\text{sin. } 60°}{\text{sin. } 40° 30'} = \frac{0.866}{0.649} = \frac{4}{3}$; that is, the sine of the angle of incidence is to the sine of the angle of refraction :: 4 : 3.

The *index of refraction*, four thirds, answers for the case where the ray passes from air into water; for other media other indices are required. Even in water a change of temperature will produce a different index. If the ray pass from water into air, the rays change names, but retain the same values; and if *n* be the index of refraction in the first case, of a ray

passing from a rarer into a denser medium, it will be $\frac{1}{n}$, when the ray traverses the same media in the reverse direction. As this minimum angle of incidence $= 0°$, that is, when the ray falls perpendicularly to the coinciding surfaces of the media, the angle of refraction must, in that case, be 0°, or the ray will pursue its course unbroken. The greatest value of the angle of incidence will be 90°; and as sin. $90° = 1$, $n = \frac{1}{\text{sin. } r}$ (when r is the angle of refraction), or sin. $r = \frac{1}{n}$. This value of n is called the *limiting angle.*

For the media air and water, $n = \frac{4}{3}$; thus $\frac{1}{n} = \frac{3}{4} = 0.75 =$ sin. 48° 35′, and this value is the limiting angle in this instance. Then a ray of light, passing from air into water, cannot have an angle of refraction greater than 48° 35′; if a ray pass at this angle from water into air, its refraction will amount to 90°, or the refracted ray will be parallel to the surface of refraction. All rays, then, proceeding from water to air, which strike the refracting medium at an angle less than the limiting angle, will not pass out, but will be entirely reflected back again, as illustrated in *fig.* 78, where the ray loses nothing of its original intensity by reflection. *Fig.* 26 represents a particular instance of such total reflection. Dip an empty glass tube, melted together at the bottom, into a vessel filled with water. By giving it a position something like that in the figure, and looking at the tube from above, it will appear as if filled with mercury. By pouring water into the tube, the metallic lustre will vanish as far as the water reaches. The phenomenon is easy of explanation, as the rays coming from *a* strike the tube at such an angle as not to be capable of entering into the air of the tube; consequently they are reflected. This reflection must, however, cease as soon as water is poured into the tube.

The amount of deviation, or the angle of deviation, may always be obtained by subtracting the angle of refraction from the angle of incidence. This deviation does not increase proportionally, as it increases with the increase of the angle of incidence much more rapidly than of the angle of refraction.

A *prism*, in Optics, is a transparent medium, bounded by two inclined sides. The line in which these two sides intersect, is called the refracting edge, and the side opposite to this the base. The angle of the two surfaces is called the refracting angle; the intersection of the prism, by a plane at right angles to the edge, is called the principal section. The three-sided prism is generally employed, bounded by three rectangular parallelograms (*fig.* 79); the principal section of such a prism is a triangle. In optical experiments, the prism is usually fastened upon a small brass stand (*fig.* 27). The rod, *t*, may be moved up and down in the tube in which it is placed, and the prism may be placed in any direction required, by means of a hinge at *g*. If the prism be fixed with the refracting edge uppermost, all objects seen through it will appear considerably displaced and raised

from their true position; in any other position of the refracting edge, they are displaced towards it, and likewise exhibit colored borders. If a beam of solar light, coming in the direction *vd* (*fig.* 28), through a small aperture in the window-shutter of a darkened room, be received on a prism with its refracting edge uppermost, an elongated space, crossed transversely by the various colors of the rainbow, will be observed. This colored space is called the *solar spectrum.* Without the prism there would have been seen at *d*, above *r*, a white and circular image of the sun.

To follow the course of the rays in a prism, it becomes necessary to consider their direction in the plane of a principal section. In *fig.* 29, let *as* and *a's* be the refracting surfaces, *s* the refracting edge of a glass prism, *li* the incident, *ii'* the refracted ray (refracted *towards* the perpendicular), and *i'c'* the ray emerging from the prism (now refracted *from* the perpendicular). For air and glass the limiting angle is $40\frac{3}{4}°$; an emergence of a ray from the prism is then impossible, when the ray, *li*, strikes the prism in such a manner, that the angle of refraction is less than the amount by which the refracting angle of the prism exceeds that limiting angle. In a prism whose refracting angle is twice as great, or still greater than the limiting angle, an emergence of the rays from the prism is impossible. If a ray of light pass in such a manner through a prism, as to make equal angles with both refracting surfaces, the total deflection produced on the ray by the prism is a minimum, that is, less than in any other position of the refracted ray. Suppose the ray, *li* (*pl.* 21, *fig.* 80), to be refracted in such a manner, that the refracted ray, *ii'*, shall make equal angles with the surfaces *sa* and *sa*, then will *ni'i* = the angle of refraction *nii'* = *x*, and the angle of deviation, *d*, of the ray at *i* = that at *i'*; the total deviation thus = D = 2*d*. If the direction of the incident ray be changed, so as, for instance, to fall along *l'i*, then the refracted ray will be *im*, and the angle, *nim*, less than *x*; the angle made by *im*, with the perpendicular through *m*, will be just so much greater than *x*: the deviation thus increases on one side and diminishes on the other. If the decrease = α, then the deviation = $d - \alpha$; as, however, it must have increased at *m* just so much more than *x*, as already seen, we may indicate the deviation at *m* by $d + \alpha + \beta$; the total deviation here, then, is $D' = d - \alpha + d + \alpha + \beta = 2d + \beta$, thus greater than D. The same may be proved by any other case of the kind. If the refracting angle of the prism be of small amount, then, in the case of the minimum of deviation, this is proportional to the refracting angle. If an object be observed through a prism, the direction in which the deviation is the least is easily found. If this minimum of deviation, *d*, be known, and the refracting angle of the prism, the index of refraction of the material of which the prism is composed, may be ascertained for air from the formula

$$n = \frac{\sin. \frac{1}{2}(d+g)}{\sin. \frac{1}{2}g}.$$

To obtain the index of refraction of any body, it becomes necessary then to form it into a prism. To give a liquid the prismatic shape, a hole is to be bored through two sides of a glass prism, and a smaller one through the

base. Upon the two first surfaces lay plates of ground plate glass, which may be kept firm by a brass clamp; fill the hollow prism thus formed with the liquid in question, through the small hole, and in it insert a stopper of ground glass. *Fig.* 30 represents a prism of this character, consisting of two hollow prisms close to each other. Another form of the hollow prism is shown in *fig.* 81. A three-sided prism of brass, or still better, of glass, is bored through, either, as in the figure, by a quadrangular, or by a round aperture; upon the two refracting surfaces plates of glass are laid, which may be pressed upon the surface of the hollow prism by means of four screws. Above is the aperture through which the prism may be filled, and which is then to be closed.

If a ray of light pass through a plate, as of glass, with parallel sides, or through several superimposed plates of different materials (*fig.* 82), it emerges in a direction parallel to the original one, though somewhat displaced from it.

The refractive power of a body is equal to $n^2 - 1$, or the square of the exponent of refraction, with respect to a vacuum minus unity; the quotient of the refracting power, divided by the density, or $\frac{n^2 - 1}{d}$, is called the *absolute refracting power.*

Arago, Biot, and especially Dulong, have instituted very accurate experiments with regard to the refractive indices of gaseous bodies; they have discovered that the refractive powers of gases are proportional to their densities. Dulong's experiments had particularly for their object the comparison of the refractive powers of gases at equal pressures and temperatures. To give them such a density as to produce precisely the same deviation, he employed a prism whose refracting power amounted to 145°, standing in connexion with a reservoir, *r* (*pl.* 20, *fig.* 31), and which could be exhausted on one side by connexion with an air-pump, and filled with gas on the other. He filled the prism first with dry air of the pressure and temperature of the atmosphere, and sighted then with a telescope set up at some distance, towards the image of a distant point refracted by the prism. The prism was then exhausted without disturbing it, and filled with another gas. By changing the pressure he could bring the refracted image of the same point of sight into the same part of the field of the telescope as before. Now, supposing carbonic acid gas to be compared with dry air, and that the pressure amounted to 18.9 inches, it is evident that as the pressure under which an equal deviation took place in air amounted to twenty-nine inches, under the circumstances the indices of refraction and the refracting power itself must be the same in air, that is, $18.9 : 29 :: 1 : x$; hence we obtain $x = 1.53$ as the index of refraction of carbonic acid at an atmospheric pressure of twenty-nine inches.

The refraction of light through lenses is of especial practical interest. Of these lenses the most important are the spherical, bounded either by portions of spheres, or by these and plane surfaces combined. Six kinds of spherical lenses are distinguished in optics, all of them represented in *fig.* 32:

bi-convex, *a;* plano-convex, *b;* concavo-convex, or meniscus, in which either the convexity is of least radius of curvature, *c*, or the concavity is of least radius, *f;* bi-concave, *d;* and plano-concave, *e*. In general, all lenses that are thicker at the middle than at the edges, are called convex or collecting lenses; and those which exhibit the greatest thickness at the borders are concave or separating lenses: *a*, *b*, and *c* belong to the former, *d*, *e*, and *f* to the latter.

The axis of a lens is that straight line which connects the two centres of the sphere, portions of which form the surface of the lens. Lenses are theoretically referable to the prism for their principle. In *fig.* 33, let *abcd* be an elongated rhomb, upon which are placed, above and below, equal parallel trapezia. Upon the trapezium *abfg*, a triangle, *fgh*, is superimposed, a similar one being placed on the lower trapezium. The two sides not parallel of the trapezium might, when produced, form an isosceles triangle, whose angle at the vertex is half the size of the angle *ghf*. If the figure thus produced be rotated about the axis MN, a lens-shaped body will be produced, which consists of several zones, and whose centre forms a plane disk. If a ray of light impinge upon this body, passing from a point of the axis MN, the deviation produced may be determined according to the laws of refraction in prisms. If the point S be so situated that a ray emitted from it and striking the surface *ag* in *i*, shall experience the least possible deviation in its passage through *abfg*, then it will cut the axis in a point, R, equally distant with S from the lens. A ray of light passing from S, and experiencing the minimum of deviation in passing through the triangle *fgh*, will, if the refracting angle of the upper prism be half that of the lower, be diverted twice as much as in *abfg* from its original direction. Hence it follows that the lower ray, S*i*, forms half as great an angle with the axis MN as the upper one; both rays, however, are refracted to R. If we suppose the broken lines *dbfh* and *cagh* to be replaced by curves whose centres lie in the axis MN, we shall obtain an actual (bi-convex) lens. We may therefore assume that there is a point, S, of the axis, all the rays coming from which and meeting the lens, are concentrated in one and the same point, R, situated at the same distance as S from the lens. The curvature of the lens from the centre to the circumference must, however, be very slight (as will be assumed in what follows), else the above condition would be impossible.

If a bi-convex lens be met by a number of rays parallel to the axis, or which come from an infinite distance in this direction, they will all be refracted to a point in the axis called the focus. The distance from the focus to the lens is the focal length (*pl.* 21, *fig.* 34). The focus is always half the distance of the points S and R from the lens. If the luminous point lie at a finite distance from the lens, on the axis, there is equally a point of union of the rays; this, however, is further from the lens than the focus of parallel rays, and will be further as the radiant point approaches nearer. It will be at an infinite distance when the radiant is in the focus of parallel rays. If the luminous point lie within the focal distance (*fig.* 83), the rays falling on the lens will not unite, but will diverge even after emerging

from the lens; less, however, than after refraction from the first surface.

In a bi-convex lens whose two surfaces are of equal radius of curvature, the focal length is equal to the radius. Plano-convex and convex meniscus lenses have likewise foci: in a plano-convex lens of glass (when the index of refraction for air and glass is assumed to be $\frac{3}{2}$) the focal length will be twice as great as the radius of the curved surfaces.

Concave lenses have no true focus, but rather a focal point of divergence. If the rays incident on such a glass are parallel to the axis, they diverge after emergence as if they came from one and the same point called the negative focus. If the incident rays be divergent, as if coming from a point on the axis at a greater or less distance from the lens, they will be made still more divergent; and the focal point of divergence will be nearer the glass the nearer the luminous point. If the incident rays be convergent (*pl.* 21, *fig.* 84), all these cases will be possible. If they converge towards the focal point of divergence, they will emerge parallel on the other side; if they converge still more than this, they emerge convergent. If they converge less, they diverge after emergence, as if they came from a point before the glass.

The preceding observations apply in general to rays coming from a point elsewhere than in the main axis of the lens, provided the line drawn from this point through the centre of the lens (the secondary axis) forms but a small angle with the principal axis. All rays proceeding from this point and incident upon the (convex) lens, are united in a point of the secondary axis, which is at the same distance from the lens as if the luminous point were situated in the principal axis.

We shall now be able to examine the formation of images of objects by lenses. In *fig.* 37, let AB be an object placed before the convex lens VW, and at a greater distance from it than the focus F. In this case, an actual but inverted image, *ab*, will be formed, which will be of the same size as the object, or greater, or less, as the distance of the object from the lens is equal to, greater, or less than twice the focal distance. In fact, image and object are always to each other in the ratio of their respective distances from the lens. If the object lie within the focus of the lens (*fig.* 38), no actual or convergent image will be formed, but an eye situated on the other side of the lens (to the right in our figure) will see the object, AB, magnified in *ab*; *ab* is therefore to be considered the image of AB. Concave lenses afford images of this latter kind; they are, however, diminished instead of being magnified (*fig.* 39). It thus appears that convex lenses alone magnify: concave lenses always diminish.

In order that all rays coming from a luminous point shall unite actually in one point, the aperture of the lens must not exceed 10°—15°. If the aperture be larger, as in the lens VW (*fig.* 40), only three rays near the axis will unite in the focus of parallel rays: the exterior ones will unite at points nearer to the lens.

Fig. 42 represents a *Fresnel* or *Polyzonal Lens*, by means of which the light of a light-house may be cast to a distance of many miles. It consists

of a spherical segment, *a*, and several rings, *b*, *c*, *d*, surrounding it, exhibited in section by *fig.* 41. Their curvature is so calculated that their foci shall coincide with that of the segment, *a*; if now a light be placed in this latter point, all rays from it, incident upon the lens, will emerge parallel. This can only take place in the common lens at a very small aperture, while in the polyzonal lens, the aperture may amount to 40°, and the desired end be still attained. It is evident that the light at *f* can be rendered visible at a great distance, as this kind of lens sends out, in one and the same direction, nine times as much light as the common lens.

d. Color.

White solar light is composed of variously colored rays, as may be shown by means of a prism (*pl.* 21, *fig.* 28) in the experiment already referred to. In *fig.* 43, let *m* be a mirror attached to the shutter of a darkened room, casting the rays received from the sun through the opening, *o*, into the chamber; let *p* be a prism, and *t* a wall receiving the images. Before applying the prism, there is seen at *g* a round white solar image. After attaching the prism, an elongated colored image, *ru*, will be perceived, of equal breadth with the direct solar image, *g* (*fig.* 44). This colored image, called the solar spectrum, is of equal breadth with the natural solar image; its elongated length depends upon the refracting angle and the refracting medium. The relation of the material of the prism to the length of the spectrum, other things being equal, is called its dispersive power, which is greater as the length of the spectrum is greater. A hollow prism, filled with water, will give a spectrum of different length from the same prism filled with sulphuret of carbon, or other liquid substance. Prisms of flint-glass have a greater dispersive power than those of common glass.

When the white band in the centre of the spectrum is destroyed by elongating the spectrum, seven principal colors will be distinguishable in the latter. These are, in the ascending order, red, orange, yellow, green, blue, indigo, and violet. These are called the colors of the rainbow, prismatic, or spectral colors; the latter, on account of their not being further separable into other colors. The red rays always appear near to where the white image stood before the application of the prism. It follows, therefore, that the different rays are of different refrangibilities, the red being least, and the violet most refracted. All media do not transmit the colored rays with equal facility; if, for example, the hollow prism (*fig.* 30) be filled with a solution of sulphate of indigo, and the circular aperture in the window be viewed through it, we shall observe only two separated images of the bright disk, a blue and a yellow. A solution of chromate of lime gives a red and green image. Hence it follows that the entire spectrum consists of circular solar images, as shown in *fig.* 44, which cover each other more or less. The less of this superposition of individual images, the more distinct will be the colors. That the colors of the

spectrum are simple, is shown from the fact, that if one be isolated and passed through a second prism, no further decomposition takes place.

As white light is resolvable into the colors of the spectrum, so these latter may be combined again to produce white light. Let the spectrum be received on a convex lens, *l* (*fig.* 45); this lens will unite the differently colored rays into a single point, *f*, and if a screen of paper or of ground glass be placed here, the solar image again appears perfectly white. If the screen be removed to a greater distance than the focal length, the spectrum will again appear, but inverted, $r'u'$. If, instead of the screen, a mirror be placed at *f*, the reflected rays will again form a colored spectrum, $r''u''$. The following is another experiment, illustrating the re-composition of light. If a disk of paper be divided into seven sections, and painted so as to resemble, as nearly as possible, the prismatic colors in their natural order, then, on giving the disk a rapid rotation, a whitish hue will be perceptible instead of the colors. The disk would appear perfectly white if the prismatic colors could be represented perfectly pure, and of their proportional spectral breadth. All the seven colors, properly combined, thus produce white; if, therefore, one of these colors be suppressed, or its proportions altered, any other tint may be obtained. If, for instance, red be omitted, a bluish tint will be perceived; on adding the red this will disappear, and white again be exhibited. Two colors, which, when mixed with each other, produce white light, are said to be *complementary* to each other. Thus, violet is complementary to green, yellow to blue, &c.

Not white solar light alone, but also the natural colors of bodies, can be decomposed by the prism. For this purpose small strips of the color should be cut off and examined through the prism. Paste, for instance, upon black paper (*fig.* 46), a series of very small strips of colored paper, about half a line in width, of the following colors, beginning at the left:—white, yellow, orange, deep red, green, blue. If these be examined by a prism whose axis is parallel to the direction of the strips, they will appear, not only displaced, but their colors decomposed. The colored image of the white paper is complete; that of the yellow is wanting in blue and violet; that of the orange in blue, violet, and green; the image of the red paper contains only a little orange in addition to the red: in the green and blue papers the red rays are wanting almost entirely.

If the colors produced by prisms of different material be examined, it will be seen that the single colors, while following each other in an invariable order, yet differ in proportional breadth. This difference in different bodies is determined by the difference of the refracting indices of the red and violet rays, and is called *the dispersion*. Thus, flint glass has in general a greater dispersive power than crown glass; and this than water. By the dispersive power is to be understood the quotient arising from dividing the dispersion by the index of refraction of the mean rays, minus unity.

If two prisms, A and B, be so combined that the refracting edges are directed in opposite directions (*fig.* 47), the one neutralizes more or less the action of the other. If the compound prism thus formed produce a refraction of light without a decomposition, it is called achromatic. A compound prism

of this character must consist of prisms of two different substances, crown and flint glass for instance, whose dimensions are so calculated that the violet rays of the one coincide with the red of the other, or vice versâ; nevertheless, a perfect achromatism cannot be obtained in this way. The possibility of producing a perfect achromatism was long doubted: Euler, Clairaut, and D'Alembert instituted many experiments on the subject. Hell, in 1733, constructed achromatic telescopes, but Dolland was the first to publish them, in 1755. Even at the present time, when so much progress has been made in practical and theoretical optics, the construction of good achromatic instruments is one of the most difficult problems.

A simple lens has actually different foci for the different colored rays, the focus of the red lying at a greater distance than the violet. The result of this is, that the images of simple lenses are surrounded by colored borders and consequently appear impure. If, now, lenses be composed of different kinds of glass, as a concave lens of flint glass united to a convex one of crown, the two rays may be so related as that the foci of the differently colored rays shall accurately coincide, and the object appear free from all colored edges. A lens of this character is called *achromatic*, and is represented in *fig.* 48. (It is wrongly marked 43 in the plate, standing immediately to the left of *fig.* 42, the polyzonal lens.) In the preceding instance, both lenses combined produce no colored dispersion at all; as, however, the flint glass has a greater dispersive power, a concave lens of flint glass capable of destroying the dispersion of a convex lens of crown glass, will not be able entirely to overcome the convergence of rays to *p*, produced by the convex lens of crown glass; the two combined will therefore act as a convex lens, and at the same time be achromatic.

e. Of Sight.

The sensation of sight, or the perception of light and color, depends upon the affection of certain nerves, whose delicate extremities are distributed and expanded in the eye as a nervous membrane, called the *retina*. It is upon this retina that rays of light proceeding from the objects of the external world, fall. The organ of sight is nevertheless very differently constructed in different classes of animals, and two essentially different kinds of eyes are distinguished—the *mosaic composite* eyes, as possessed by most insects and crustacea, and the *simple eyes* provided with convex lenses, possessed by man and the other vertebrata.

A *mosaic composite* eye (*fig.* 49), is so arranged that a great number of transparent truncated cones stand perpendicularly on a convex retina. Those rays alone can reach the bottom of one of these cones which fall along the direction of its axis; all rays coming sideways are absorbed by the dark pigment clothing the sides of the cone. In *fig.* 49, let *fcbg* be a section of the convex retina, with the transparent cones set upon it. Rays passing from the luminous point A, can strike this retina only in *cb*, the base of the truncated cone, *abcd*. Any other luminous point, B, must

send its rays to some other point of the retina. The greater the number of cones the greater the clearness of the image. The transparent cornea coating externally the summits of these cones, is divided into a great number of facets, whose number, in some eyes, amounts to from twelve to twenty thousand, each one corresponding to the truncated cone just described. The size of the field of vision depends upon the angle which the axes of the outermost cones make with each other.

In simple eyes, the images are produced in the same way as the convergent images of convex lenses. The rays proceeding from any point and passing through the anterior portion of the eye, are refracted to a point in the retina. The following is the structure of the human eye as shown in *pl.* 21, *fig.* 50. The ball of the eye is inclosed in a tough, opake, white membrane, called the *tunica sclerotica*, which is anteriorly replaced by the transparent *cornea*. Immediately behind the latter is seen the colored *iris*, whose central perforation, *ss'*, is called the *pupil*. Behind the pupil, and inclosed in a transparent membrane, is the *crystalline lens*, *cc'*, most convex posteriorly. Between the crystalline lens and the cornea is a transparent liquid called the *aqueous humor*. The internal cavity of the eye, behind the lens, is occupied by a gelatinous liquid of perfect transparency, called the *vitreous humor*. This is inclosed in a capsule, subdivided by numerous partitions. The *choroid* membrane lines the inside of the sclerotic coat, and is itself invested with a black coating called *pigmentum nigrum*. Lining the choroid, with its pigmentum nigrum, is the *retina*,—a delicate expansion of the optic nerve.

All rays impinging upon the eye fall either on the sclerotica (the white of the eye) and are then dispersed irregularly in every direction, or they penetrate the cornea. Of these, the most external meet the iris and are absorbed, the central ones only passing through the pupil to be refracted still further by the crystalline lens and vitreous humor. Rays of light, then, proceeding from the individual points of an object, are refracted to a point on the retina, producing an inverted image. In the figure, *m* is the image of the point *l*, *m'* that of *l'*. All objects not too near the eye are seen with distinctness; there is, however, a limit, within which the images of objects become confused. This, which for ordinary eyes amounts to about five inches, is called *the limit of distinct vision*. The indistinctness is produced by the great divergence of rays proceeding from objects in very close proximity, and their refraction towards a point posterior to the retina.

Although the ordinary eye *can* see distinctly at a distance of five inches, yet the ocular examination of minute objects, as the letters of a book in reading, is generally performed at a distance of from ten to fourteen inches. Persons who are obliged to hold objects much nearer than this to the eye, are said to be *short-sighted;* and if at a greater distance, *long-sighted*. These defects of vision are remedied by the use of lenses; concave being required for the first, convex for the last.

Achromatism in the eye is effected in the same manner as in lenses, light traversing three different media. This achromatism, although not complete in all cases, is yet so nearly so as to answer all necessary purposes.

The apparent size of an object depends upon the amount of the *angle*

of vision. This is the angle (*pl.* 21, *fig.* 85) formed with each other by the two lines, A′*a*, B′*b*, drawn between the corresponding extremities of the object and its image on the retina. Two objects of different magnitude, as AB and A′B′, may appear of the same size when their actual size is proportional to their distance from the eye. When the angle is less than a certain limit, the object becomes invisible.

An image of an object is formed in both eyes; we *see* but one, however, as soon as the eye has been adjusted properly to the distance of the object. When the eye is arranged for a distance greater or less than the true one, the object will be seen double. In *fig.* 51, let L and R be the two eyes, A and B two objects at different distances from them. If the eyes be fixed upon the nearer object, A, the optical axis will be directed towards A, so that its image falls in the middle of the retina, at *a* and *a′*. The object, A, is seen single; B, however, appears double, its image falling out of the centre of the retina at *b* and *b′*. The case is reversed when the eyes are directed to B.

Several objects may be seen single by both eyes when their images fall on corresponding parts of their retinas. In *fig.* 52, let L and R again represent the two eyes, A, B, and C, three objects before them. All three will be seen single, and at the same instant, as their images follow each other in the same order in both eyes.

By *irradiation* is meant the fact, that a bright object on a dark ground appears to us magnified, while a dark object on a bright ground seems to be reduced in size. The apparatus represented in *figs.* 53 and 54 is intended to illustrate this phenomenon. *Fig.* 53 represents a piece of pasteboard, whose upper half is covered with a piece of white paper, and the lower with black. The former is bisected by a narrow strip of black, about two lines in breadth, the latter by a strip of white of the same breadth, and in the same line with the black strip. On placing the pasteboard near a window, the white strip will, at a certain distance, appear decidedly broader than the black.

The following experiment shows that irradiation is not equally strong for all persons. Paint upon a piece of white pasteboard two equal, rectangular, black spaces, so that the border, *al* (*fig.* 54), shall be about half a line to the right, and the border, *gh*, about the same distance to the left of the vertical central line of the pasteboard. If this be observed at a certain distance, the edges, *al* and *gh*, will appear to lie in the same straight line; the precise distance necessary for this result will, however, vary considerably for different persons.

Very small objects on a white ground, vanish entirely when looked at under certain conditions, the principal of which is the falling of the image on the so-called *punctum cæcum*, that part of the retina at which the optic nerve enters. To illustrate this disappearance of an object, lay upon the white horizontal surface, *nn′* (*pl.* 21, *fig.* 86), two small dark disks, from one to four lines in diameter, and about three inches apart. Bring, now, the right eye vertically over the left disk (or the left eye over the right disk), and at a height about five times as great as the distance between the

disks. If, in the first mentioned case, the left eye be closed and the left disk steadily looked at, the right disk will completely disappear, on account of the falling of its image on the punctum cœcum. The experiment, to be successful, may, for particular individuals, require a variation in the vertical height of the eye, as also in the distance between the disks.

The impression of an object upon any point of the retina lasts for an appreciable length of time after the object has been withdrawn. For this reason, a burning coal, swung quickly round, exhibits the appearance of a luminous circle. A circle (*fig.* 87) whose sectors are alternately white and black, will, when rotated rapidly, exhibit a grey color. If, on one side of a circular disk, a horse be painted, and on the other a rider, and the disk be rotated rapidly on the transverse diameter as an axis, the rider will appear to be seated on the horse.

The motion of an object may be sometimes so rapid as to produce no impression on the retina. Thus, in the case of a wheel in very rapid motion, the spokes will disappear entirely, leaving nothing visible but the circumference and the centre.

The *Phenakistoscope* (*fig.* 55) is an ingenious apparatus constructed to illustrate the principle of the duration of the impression of light on the retina. This is a disk of six to nine inches in diameter, which can be turned rapidly about a horizontal axis, and near whose edge there are several holes (eight in our figure) at equal distances apart. Inside of these apertures is attached a smaller painted disk, on which one and the same object is painted in various successive positions, each hole corresponding to one of these. Our figure represents a pendulum in its various positions. The apparatus is now to be held before a mirror, with the painted side towards it, so that the image may be seen through one of the openings, the upper for instance. By revolving the disk rapidly, the optical impression produced will be that of an oscillating pendulum. Other objects besides a pendulum may be used, and the movements of men and other objects may be simulated with the most remarkable success, by a proper arrangement of the various positions. Faraday has examined these appearances with great care, and tried many experiments on the subject. He found that when the number of the images is less than that of the holes through which they are observed, the images appeared to change their place, and go backwards. The contrary was the result when the number of images exceeded that of the apertures.

Impressions of colors which do not exist in surrounding objects are often experienced by the retina. Such colors are called *subjective*. Here belong the so-called *after-images*. If we gaze intently at the flame of a candle, and then closing the eye, direct it towards the dark side of the room, the flame will appear to be distinctly visible, becoming in succession, yellow, orange, red, violet and greenish blue, finally vanishing entirely. If the eye be directed towards the bright side of the room, the colors will be presented in an inverse order. Again, if we look at the dark frames of a window, relieved against a clear sky, and then closing the eye, direct it towards a white wall, we shall see a light frame with intervening dark spaces.

f. Of Optical Instruments.

Optical instruments are divided into *catoptric*, or those in which mirrors are used; *dioptric*, or those employing lenses; and *cata-dioptric*, those in which mirrors and lenses are combined. A single exception to this classification is perhaps to be found in the *camera lucida* of Dr. Wollaston. This is an instrument much used in obtaining the outlines of an object. It consists of a four-sided prism, *abcd* (*pl.* 21, *fig.* 56), having a right angle at *b*, an obtuse angle of 135° at *d*, and acute angles of 67½° at *a* and *c*. The prism is to be turned with the side *bc* towards the object. A ray coming from the object in the direction of *x*, enters the side *bc* perpendicularly, passing then without refraction to *dc*. Here it experiences total reflection from *dc*, in the direction *rr*, and again from *ad* in the direction *rp*, perpendicular to its original direction, *xr*. The image of the object will then be reflected to the eye placed at *p*, and as we see objects in the direction in which rays from them enter the eye, the object in question will appear in a direction *pr*. The eye must be so placed that the pupil may be bisected by the edge, *a*, of the prism; the image then being seen by the anterior half of the retina, and the point of a pencil by the posterior, the outlines of the former may readily be traced by the pencil. The prism is generally inclosed in a box, and erected on a frame (*fig.* 104) with various subsidiary apparatus.

The object of the camera lucida is also attained by the *camera obscura*, an instrument which may have a great many different constructions. The simplest of these is shown in *fig.* 58. This consists of a tolerably high pyramidical box, truncated above. Through the top passes a tube containing a convex lens. Over the upper end of the tube is placed a plane mirror, forming an angle of 45° with it. Rays coming from external objects are reflected by the mirror through the tube, falling finally upon a sheet of paper placed on the bottom of the box. A diminished image is thus produced by the help of the lens, and access being had by means of a hole in the side, the outlines may readily be traced with a pencil.

Another form of the camera obscura is exhibited in *fig.* 57. This consists of a box, ABCD, with a narrow neck, *abcd*, in which a convex lens, *bc*, is attached. This is turned towards the object in question, rays from which, after passing through the lens, are reflected by the mirror, *ef*, to a plate of ground glass at *ik*. A distinct image of the object will here be visible. The glass *gh* serves to keep off extraneous light. The *camera clara* differs from this arrangement in having a large lens in place of the ground glass. Upon this the image is depicted in sharp outlines and lively coloring.

Among the more important optical instruments are, the *microscope* for viewing very minute objects at short distances, and the *telescope* for viewing large objects at great distances. A simple *microscope* is one in which the first image formed is received unchanged on the retina. It may consist of several lenses; generally, however, of but one. The common lens is a single

simple microscope. The shorter the focus, or the greater the convexity of the lens, the greater the magnifying power. The apparent increase in the size of an object by a lens, depends upon its enabling us to see the object distinctly at a much less distance than with the naked eye, the angle of vision increasing with this proximity. The magnifying power of a lens is obtained by dividing five inches, the limit of distinct vision, by the focal length of the lens. If this be $\frac{1}{2}$, 1, 2 inches, the magnifying power will be 10, 5, 2.

The *compound microscope*, in its simplest form, consists of two convex lenses; one of short focus, called the *objective* or *object-glass*, the other of longer focus, called the *ocular* or *eye-glass*. To the latter the eye is applied. The object being placed in the focus of the objective, an image of it is formed in the ocular. This first image is magnified by the ocular, the second image being painted on the retina. The object of course appears considerably larger after the second magnifying than after the first.

Fig. 61 represents an improved form of the instrument as constructed by Chevalier, of Paris. Here the objective is at *b*, the ocular at *c*. Rays from the object, placed on the stage, *f*, of the microscope, after passing vertically through the objective, strike on the inside of the hypothenuse of the three-sided glass prism, and are reflected horizontally along the axis of the ocular tube.

To remedy the deficiency of light which always exists in the use of higher powers, the stage, *f*, has a central perforation. A plane or concave mirror, *m*, is so adjusted as to reflect rays of light through the perforation of the stage on the object. The light may be derived from the sun, from a white cloud, from the sky, or from a lamp.

The stage, *f*, is attached to a slide or socket, *d*, which, by means of a rack and pinion arrangement, can be moved up and down the rectangular bar, *g*. This adjustment is necessary to enable objects placed on the stage to be brought nearer to, or more remote from the objective, as the different focal lengths may require. Two other screws, *k* and *q*, serve to bring all the different parts of the object successively into the focus, by communicating to the stage a backward, forward, or lateral motion. The instrument may be rendered vertical by removing the part containing the prism, and attaching the objective directly to the tube containing the ocular. The objective may consist of a single lens, or of two, and even three: they should be achromatic, however. The ocular, also, in addition to the simple eye-glass, comprises a *field glass*, a second lens, generally plano-convex, whose object is to increase the field of view. For further information on this extended and interesting subject, we must refer our readers to professed treatises on the microscope, as those of Vogel, Pritchard, Goring, Ross, Chevalier, Quekett, and others.

The *Solar Microscope*—a simple microscope in principle—is represented in *fig.* 59. The mirror, *m*, reflects the light of the sun to the tube, *t*, in a direction parallel to its axis. The lens, *ir*, causes the rays to converge somewhat; a second lens, *f*, brings them to a focus, in or near which the object to be magnified is placed. This second lens can be moved backwards and

forwards by a rack and pinion: p and q' are square plates of brass, united at the corners by small posts. About each post is wound a spiral spring which presses a third plate, q, against q'. The glass slide to which the object is attached is held between the two plates, q and q'. The lenses just described serve only to throw an intense light on the object. The magnifying is produced by means of a third lens, l, which should be achromatic. This also can be adjusted, with respect to the object, by a rack and pinion. Rays of light, passing from the highly illuminated object through the lens, l, will be refracted by it into an image, whose size depends on the distance from the lens at which it is received on a screen. Should this distance be ten or twenty feet, the image will be of enormous size. When, instead of solar light, that from the oxy-hydrogen blow-pipe is employed, we have the *oxy-hydrogen microscope.*

The *Magic Lantern* (*figs.* 102 and 103) is the same in principle with the solar microscope. This consists of two lenses, behind which is placed a lamp, and between them the object. The light from the lamp is concentrated by the first lens, and thrown on the object. This being in the focus of the second lens, has an image formed of itself on the other side, and falling on a wall or on a screen placed at the distance of some feet. Here, as in the case of the solar microscope, the size of the image, the necessary adjustments being all made, will be greater with the distance of the screen from the lens. What is gained in the size of the image, will, however, be lost in its brightness, this increasing with the proximity of the screen. A proper medium must therefore be selected which shall combine both elements of the picture. The construction of the accessory parts of the magic lantern will be sufficiently evident from the figure.

Telescopes are divided into two classes, *refracting* and *reflecting*. In the former, the images of distant objects are formed by a convex lens; in the latter, by a concave mirror or speculum. The refracting telescope, again, may have different constructions. In the oldest of these, or the *Galilean* (*fig.* 65), the ocular is a single concave lens, XZ. VW is the objective, which, of itself, would produce an inverted and reduced image of a distant object at *ab;* the rays, however, before uniting in an image, fall upon the concave eye-glass, XZ. The eye-glass is so placed that the distance of *ab* is slightly greater than the dispersive distance of XZ; accordingly, rays converging to one point of *ab*, are refracted by the concave lens, so that after their passage through it, they diverge as if proceeding from a point before the glass. The rays converging towards *b*, diverge there as if coming from B; those converging from *a*, as if they came from A. An erect and magnified image, AB, is thus produced. The magnifying power of the *Galilean* telescope is as the ratio of the focal distance of the object-glass to that of the eye-glass.

In the *Astronomical* or *Keplerian Telescope* (*fig.* 66), the ocular, instead of being concave, is a convex lens. Here the objective produces an inverted image, *ab*, which is magnified by the ocular, in which case its image, still inverted however, is referred by the eye to AB. In the *terrestrial telescope* the ocular or eye-piece consists of four convex lenses, for the purpose of

exhibiting objects erect. To determine the magnifying power of the astronomical telescope, divide the focal distance of the object-glass by that of the eye-glass. As, however, this focal length may not always be known, the magnifying power may be determined by experiment. Set up at some distance from the telescope a graduated staff. Look at the staff with one eye unarmed, and with the other through the telescope, simultaneously. By observing how many degrees of the staff, as seen with the naked eye, correspond to one as seen magnified through the telescope, we shall be able to determine the magnifying power.

The essential part of the *reflecting* telescope consists of a concave mirror or speculum. This, when placed before the object, produces an inverted image of it, which may be viewed in various ways. In the *Gregorian* telescope (*fig.* 62), the concave mirror, *mm'*, has a circular aperture, *cc'*, in the centre. Rays falling upon the mirror are reflected so as to produce an inverted image of the object at *ii'*, just in the focus of a second small concave mirror. This again inverts the image, casting it erect before the ocular. The ocular generally consists of two lenses,—an eye-glass proper, and a field glass for increasing the field of vision. By means of the screw *bs*, the position of the smaller mirror with respect to the ocular may be varied.

In the *Cassegrainian telescope*, instead of the small concave mirror a convex one is employed (*fig.* 63). This mirror receives the rays from the concave mirror before their union. In this way an inverted image, *ii*, of the object is formed between the two lenses of the ocular, to be further magnified by the eye-piece.

In the *Newtonian telescope* (*fig.* 64), the rays reflected from the concave mirror fall on a plane mirror placed at an angle of forty-five degrees, and are cast into the axis of the ocular, placed in the side of the tube at *o*. In this arrangement there need be no perforation of the large mirror. For further information respecting telescopes we would refer our readers to the article *Astronomy*.

g. Of the Interference and Diffraction of Light.

Two very different hypotheses have been suggested as to the actual nature of light. That of emission, or emanation, assumes the existence of an exceedingly rarefied matter, emitted or projected from a luminous body in every direction. The hypothesis of oscillations or undulations, on the other hand, supposes an almost inconceivably subtle medium called ether, which fills all space, even the pores of bodies, oscillations in which produce the physical phenomena called light. At the present time the latter is most generally adopted, though the former does not lack the authority of great names, among which that of Newton stands pre-eminent.

The facts which most strongly countenance the undulatory theory of light are those derived from the phenomena of interference, phenomena which this theory alone can fully explain. These are, that rays of light

meeting at a very acute angle do not necessarily produce an increased intensity of illumination, but may sometimes cause total darkness by their coincidence. An experiment of Fresnel's illustrates this very satisfactorily. Two metallic mirrors, *mc*, *m'c* (*pl.* 21, *fig.* 68), are so placed that their planes are vertical, and form a very obtuse angle with each other. Let *f* be a luminous point sending rays to both mirrors and giving rise to the images, *p*, *p'*, lying tolerably near to each other. At a certain distance from the mirror the reflected rays meet each other, and form alternately light and dark stripes. If, for instance, the point *b* lie at an equal distance from *p* and *p'*, there will be a bright stripe at *b*, dark ones on each side at *s* and *s'*, bright ones again at *b'* and *b''*, and dark ones at *s''* and *s'''*, &c.

Instead of the metallic mirrors, two equal oblong plates of polished glass may be laid on a block of wood, touching each other along one edge. They should rest at each end on pieces of soft wax, so that by pressing them down when they are in contact, the planes of the two may be made to assume a very obtuse angle with each other. *Fig.* 88, *pl.* 21, exhibits a view of this arrangement.

It will be necessary to explain more fully the principles of the undulatory theory, before these and the other phenomena of interference can be clearly understood. If a ray pass from A to B (*fig.* 89), all particles of ether lying between A and B oscillate up and down in directions perpendicular to AB. The particle whose position in a condition of equilibrium is at *b*, oscillates constantly between *b'* and *b''*. At these two points its velocity is zero, this increasing constantly as the particle approaches the position of equilibrium, *b*, where it attains the maximum. The interval between two particles, *b* and *c*, which vibrate in the same phase, is called the *wave length*. It is to be observed, however, that *c* begins its first oscillation when *b* commences its second in the same direction. A particle, *f*, half way between *b* and *c*, will always be in a phase of vibration directly opposite to them, attaining its maximum of deviation below AB, when these have reached their maximum on the opposite side. They are, in this case, said to be *half a wave length apart*. In general, then, two particles of ether, half a wave length apart, in the path of a ray of light, will be affected by equal and opposite velocities. The same applies to such as are distant $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$ of a wave length. The length of a wave and the deviation of an oscillation differ for the different colors, being greatest in the red, and least in the violet.

To apply the preceding principles to the explanation of the phenomena of interference, suppose rays proceeding from *f* (*pl.* 21, *fig.* 68) to be reflected from the mirror, *cm*, as if they came from *p*, all the oscillations producing the ray *gb* being perpendicular to its path. Let a circle be drawn through *b* from a centre *p*; all points, *s*, *b'*, *s''*, &c., lying in this circle, will be simultaneously placed in the same condition of oscillation by rays reflected from the mirror, *cm*. Our figure represents other concentric arcs drawn about *p*, the interval between two full arcs representing a whole wave length, and that between a full arc and a dotted one, only half a wave length. A similar series of concentric arcs has been described about *p'*.

Now, as the particle of ether at b is equidistant from p and p' ($fgb = fhb$), it will receive an impulse from both systems of waves, at the same instant and in the same direction. The intensity of oscillation will thus be doubled, and with it the amount of light. On the other hand, the particle, s, will be impelled at the same instant with the same intensity, but in a diametrically opposite direction. The oscillation of the particle of ether being thus neutralized, darkness at s must be the result. And, in general, in a system such as we have represented, increased illumination will be found to occur whenever the homogeneous circles intersect, while darkness will result from the intersection of a dotted circle or arc, and one that is continuous.

Fig. 90 illustrates still more fully the principle of interference. Let the lines AB and CD here represent two rays of light, which, proceeding from the same source, intersect each other in a very acute angle in a, reaching this point by different paths. If the distance traversed by the one ray, after leaving the original starting point, be as long as, or longer by one, two, three, ... n, entire wave lengths, than the path of the other ray, the two will act in concert on the particle of ether at a, and the intensity of light will thereby be increased. If, on the other hand, the path of the ray be $\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \ldots \frac{n}{2}$ that of the other, darkness will ensue at their meeting. When the difference of the interfering rays falls between the limits of a multiple of whole wave lengths, and an odd multiple of half wave lengths, the effect produced will be intermediate between a double intensity of light and total darkness.

To explain the *reflection* of light by the undulatory theory, let am (*fig.* 91) be a ray impinging at m upon mk, the surface of union of two media. Let $a'm'$ be a second, and $a''k$ a third ray from the same source: if this be at a very great distance, all these rays may be assumed to be parallel to each other, and the wave surface passing through m and n to be plane. This plane wave meets the surface of union (or separation) first at m, later at m', and still later at k. While the wave is proceeding from n to k, a spherical wave is propagated from m, the first point of impact, with a radius $mo = nk$. Moreover, if $m'n'$ be parallel to mn, the spherical wave propagated from m' will have acquired a radius, $m'o' = n'k$, in the time required for the upper wave to pass from n' to k. In a similar manner spherical waves will be propagated from all points lying between m and k, and a surface, tangent to all of these at the same time, will be the reflected wave. Now, as $mo : m'o' :: nk : n'k :: mk : m'k$, the tangent surface will be plane. The rays which the reflected wave produces, namely, ml, $m's$, kr, &c., are all perpendicular to ok, and answer to each other, the corresponding particles of ether, l, s, r, &c., being always in similar phases of oscillation or vibration. Finally, as the triangles nkm and omk are equal, the homologous angles nkm and omk are equal, according to the well-known law of reflection.

The *law of refraction* is explicable in a similar manner. In *pl.* 21, *fig.* 92, let mk be the surface of a transparent medium, met at m, m', and k, by

parallel rays, and *mn* the position of the incident plane wave. At the moment that this wave reaches *n*, a system of spherical waves will be diffused in the two contiguous media, which, however, will be propagated with unequal velocity in the two media, owing to the different elasticity of the ether contained in them. Supposing the second medium to be more refractive than the first, then the wave propagated in it from *m*, will reach the surface of a sphere, whose radius, *mo*, is less than *nk*, in the same time that the plane wave occupies in traversing the space *nk*. Moreover, the plane wave reaches *m'* and *n'* simultaneously, and passes from *n'* to *k*, while the corresponding spherical wave expands from *m'* to the surface of a sphere, whose radius *m'o'* is to *mo*, as *n'k* to *nk*. Hence it follows that all spherical waves, dependent upon the same incident plane wave, and proceeding from the different points between *m* and *k*, are tangent to one and the same plane, *ko'o*, parallel to which the refracted wave is propagated. As the lengths, *nk* and *mo*, are as the velocities of transmission of light waves in the two media, their ratio will be a constant one, or $\frac{nk}{mo} = m$, the symbol assumed for this ratio. Now we have $nk = mk \sin. nmk$, and $mo = mk \sin. mko$; therefore, by eliminating *mk*, substituting the symbol *m* for the ratio $\frac{nk}{mo}$, and reducing, we shall have $\frac{\sin. nmk}{\sin. mko} = m$, or $\sin. nmk = m \sin. mko$. By erecting a perpendicular to *mk* at *m*, it will be readily seen that the angle *nmk* = the angle of incidence of the ray, and *mko* = the angle of refraction.

A remarkable phenomenon first discovered by GRIMALDI of *Bologna*, is the *diffraction of light*, that deviation or deflection experienced by rays of light in passing by the edges of opake bodies. Thus, allow a solar ray to enter a dark room through a small aperture, and into the axis of the ray introduce a very thin plate of metal, with a very minute hole bored through it. If the light passing through this hole be received on a white screen, instead of a simple white spot there will be perceived one surrounded by several rings. If a fine slit be made in the metal plate, instead of the circular aperture, streaks parallel to the slit will be observed, which are alternately light and dark. Experiments on this subject are best conducted by examining the phenomena through a closely approximated telescope.

Fig. 93, *pl.* 21, represents the appearance presented by looking through a narrow slit at a point or line of light, homogeneous light, as that produced by interposing a piece of red glass, being employed. In the middle is seen a very bright stripe, and on each side others of sensibly diminishing brightness, separated by dark intervals. These are called by FRAUNHOFER *spectra of the first order*. A parallelogram-shaped aperture presents the appearance seen in *fig.* 94; a circular one that in *fig.* 95. A few brief indications are all that we can here present of the explanation of these phenomena afforded by the undulatory theory of light. If the light from a distant point fall perpendicularly upon the plane of the screen AB, in which

is the aperture CD (*fig.* 96), we may consider all the particles of ether at the opening as being in similar phases of vibration. Each one propagates its vibrations in every direction beyond the screen, and the intensity of illumination at any point, *s*, on the other side of the screen, depends upon the result produced by the interference of rays passing through different points of the aperture CD and meeting in *s*. Hence it follows that rays transmitted at right angles to CD will strengthen each other, and consequently give rise to a bright stripe or spot in the centre, while on each side or around this centre, dark and light stripes or circles must alternate. The phenomena exhibited by a parallelogram-shaped aperture (*fig.* 94) are produced in a similar manner. Thus, the parallelogram *abcd* (*fig.* 97) forms a part of a vertical slit, and therefore presents a succession of horizontal spectra, while the edges, *ab*, *cd*, form part of an obliquely transverse slit, and produce spectra following each other in the direction of the line *lm*, perpendicular to the edges *ab*, *cd*.

If two or more diffracting apertures of equal size and shape stand near each other, the same figure as that produced by a single one will be seen, only intersected by many black stripes. These, according to Fraunhofer's terminology, convert spectra of the *first* order into those of the *second*. Through two parallelogram-shaped apertures we have the appearance represented in *fig.* 98, and through three circular ones that in *fig.* 99.

Peculiar phenomena, first discovered by Faraday, are observed whenever we look through a telescope, before which is placed a fine wire grating, at a line of light parallel to the intervals of the grating. If white light be employed, smaller colored spectra are produced, intermixed with black interspaces. If, instead of the grating, a fine gauze be used, the spectra, radiating from a centre, present a highly beautiful appearance.

Colors of thin plates.—If a glass lens of great radius of curvature be pressed upon a flat plate of glass, a series of concentric colored rings will be observable around the central dark point of contact. These are also observed in the case of thin films of oil, metallic oxides, &c.; in fact, the illustrations of the phenomenon may be varied infinitely. They are all explicable on the undulatory theory, by the interference produced by the reflection of rays from the upper and under surfaces of the thin plate, this consisting, in the first-mentioned experiment, of the film of air interposed between the two plates of glass. The different degrees of interference between the two sets of reflected rays, produce the various shades of color and light. Light transmitted through thin plates also exhibits the colored rings or bands, these being complementary to colors of reflection. Thus, if in the first-mentioned experiment, the colors reflected are *black*, *blue*, *white*, *yellow*, *red*, those transmitted will be in succession, *white*, *yellowish red*, *black*, *violet*, *blue*, &c. Below and above a certain thickness of the plate, these colors cease to be visible, this thickness varying with different media. Thus for air the minimum is half a millionth of an inch, the maximum seventy-two millionths; for water, three eighths of a millionth,

and fifty-eight millionths; for glass, one third of a millionth, and fifty millionths.

The *iridescence* of mother-of-pearl, and other surfaces, is explicable in a similar manner. All such surfaces are found to have very fine parallel striæ or grooves impressed upon them, a cast of which may readily be taken by means of soft wax. In this case the wax itself will show signs of iridescence. The colors, therefore, are produced by the interference of the light reflected from the bottom of the groove, with that reflected from the top.

The colors of thin plates, or the Newtonian rings, may also be exhibited by reflecting a narrow beam of solar light in a dark room upon a screen; the mirror used must be concave, and of glass, with its axis coincident with the direction of the ray.

h. Of Polarization and the Double Refraction of Light.

A ray of light is said to be polarized when it does not, as in ordinary rays, possess the same properties in every direction, with respect to reflection and refraction. If, for instance, an ordinary ray, *ab* (*pl.* 21, *fig.* 100), falls at an angle of 35° 25′, upon a plane plate of glass, blackened at the back, it will in greater part be reflected in the direction *bc*, according to the usual law; this latter ray, *bc*, is now polarized. Should this ray fall upon a second blackened plate, similar to the first, and parallel to it, it will be reflected a second time, and, indeed, in the same plane. If now the second plate be rotated about the ray *bc*, still retaining the same angle of incidence, the plane of reflection will be changed, and the intensity of the twice reflected ray will diminish with the increase of the angle between the two planes of reflection; when this amounts to 90° the intensity of the ray will be 0.

When two glass mirrors of the kind just described are combined, so as readily to admit of experiment in polarization, they form a *polarizing apparatus* or *polariscope*. *Pl.* 21, *fig.* 69, represents an instrument of this kind, as given by Nörremberg. Two uprights are fixed firmly in a heavy foot, and inclose towards their lower end a frame, B, turning between these on a horizontal axis. The frame carries a polarizing glass mirror. The mirror is usually fixed with its plane at an angle of 35° 25′ with the vertical. A ray, *ab*, incident at this angle upon the mirror is partly transmitted, partly reflected; the reflected ray (now become polarized) takes the direction *bc*, and striking a plane mirror at *c*, is reflected back in the same direction, passing through the uncovered mirror, B, to the upper part of the apparatus. This upper portion sustains a ring graduated to degrees. Inside of this ring turns a second ring, with two small posts, between which is placed a second mirror, also turning on a horizontal axis. This mirror is of glass, blackened at the back, and is called the analysing plate or mirror, the lower one being the reflecting. An index

line is drawn through the middle of the anterior half of the inner ring, which has its edges somewhat bevelled; a vertical plane passed through this line and the centre of the ring, would be parallel to the plane of reflection from the upper mirror. When the index stands at 0° or 180°, the planes of reflection of the two mirrors coincide; they are perpendicular to each other when the index points to 90° or 270°. If the upper mirror, like the lower, be adjusted at an angle of 35° 25′ with the vertical line, the index standing at 0° or 180°, then a ray from the lower mirror will be reflected, and the field will appear bright; if, on the contrary, the index stand at 90° or 270°, this same field will be dark. Thus, from 0° to 90° the brightness decreases; from 90° to 180° it increases; from 180° to 270° it decreases again; and from 270° to 180° it again increases. There is generally a second ring interposed between the two mirrors, upon which a glass plate may be laid, to hold objects which are to be examined by polarized light.

The preceding angle of 35° 25′ is that in which the light reflected from glass is completely polarized; this is then called the *angle of polarization*. At any other angle the polarization will be only partial or incomplete. Every substance has its angle of complete polarization, this being obtained, according to Brewster, by the following formula: the index of refraction is the tangent of the angle of polarization. In *pl.* 21, *fig.* 70, if *si* be the incident and *fi* the reflected ray, *fir* a right angle, then *fif′* will be the *angle of polarization*. A plane passed through *abc* (*fig.* 69) is called the *plane of polarization*. When a ray is polarized by reflection, as in the illustrations already adduced, its plane of incidence is at the same time its plane of polarization.

Rays of light may also be polarized by refraction. Thus, if a ray be incident on a transparent glass plate, at the angle of polarization, it will be partly reflected and partly refracted. The reflected portion will be polarized, and the refracted also, but in a less degree. By employing a bundle, consisting of several glass plates, the polarization of the refraction will be increased in intensity. An arrangement of this latter character may be substituted for the analysing plate in the apparatus represented in *fig.* 59, by removing the upper ring with its plate, and replacing it by a ring carrying a hollow cylinder. In this cylinder is to be placed the tube (*fig.* 101), with its bundle of glass plates, as represented in the figure.

The analysing plate of the polariscope (*fig.* 69) may also be replaced by a plate cut from a crystal of tourmaline, the surfaces being taken parallel to the principal axis. Even common light will be polarized by passing through such a plate. Two plates of this character applied to each other, with their axes parallel, transmit light like a single plate of the same thickness. By rotating one of them on the other, the same variations in the intensity of light as in the polariscope will be presented: a diminution from 0° to 90°, and from 180° to 270°; an increase from 90° to 180°, and from 270° to 360°.

In the phenomena of *double refraction* we have another illustration of polarization. Certain transparent bodies possess the property of splitting

every single ray, incident in certain directions, into two. One of these rays will be refracted according to the usual principles of refraction, hence called the *ordinary ray;* the other, or *extraordinary ray*, follows quite a different course through the medium. This latter ray is polarized. The experiment is easily performed by making a small dot of ink on paper, and laying a crystal of Iceland spar over it. Two images of the dot will be seen, much to the surprise of every one who observes the phenomenon for the first time. This property was first observed in crystals of carbonate of lime, or Iceland spar, hence sometimes called double-refracting spar; it is not confined, however, to this mineral substance, belonging generally to all crystals whose primitive form is neither a cube nor an octahedron. In all doubly-refracting bodies there is one, and in some, two or more directions, along which, objects, when viewed through them, appear single; these are called the lines or axes of double refraction. When the extraordinary ray is refracted towards this axis, the crystal is said to be *positive;* when from it, *negative.*

Doubly-refracting crystals are sometimes applied to telescopes to measure the diameters or distances of objects. A telescope provided with such an apparatus is called a *Rochon's micrometer*, from its inventor. The prism is movable, and placed between the objective and ocular. Let *c* (*pl.* 21, *fig.* 71) be a convex lens, casting an image of a distant object on a screen at *fm.* By interposing a prism of the proper character (generally two equal prisms of rock crystal cemented together) between the image and the lens, the ordinary ray will form an image at *fm*, while that of the extraordinary ray will be at *f'm'*. The distance between these two images increases with that of the prism from the screen, and decreases with the approximation of the latter; the prism may then be brought so near to the screen that then the edges of the two images shall be in contact, as in *fig.* 72. The same reasoning applies when the lens *c* is the objective of a telescope, and the images are seen through its ocular. We shall then have the following formula for the tangency of the images: tang. $v = \frac{h}{f}$ tang. *e;* where *z* represents the centre of the prism, *e* the angle *fmz*, *v* the angle *fcm*, *f* the focal length of the objective, and *h* the distance of the prism from the image. Now the values of *f* and the angle of deviation, *e*, are constant; *h* also is measurable by means of a graduation attached to the outside of the telescope, consequently the angle *v* can be ascertained from the formula. This angle is equal to that at which the object appears without any telescope, or the apparent diameter: knowing this, therefore, either the actual diameter or the distance of the object can be found, the other being known.

A remarkable phenomenon of polarization is found in the brilliant colors produced by interposing thin plates of various substances between the two mirrors of the polariscope (*fig.* 69). These colors and their brillancy have been found to depend both upon the situation of the laminæ and the relative position of the polarizing mirrors. If, for instance, the colors produced be of greatest intensity when the planes of the mirrors are at

right angles to each other, then the colors will become enfeebled by rotating the upper mirror. When the angle of rotation amounts to 45°, then the colors will disappear almost altogether. Continuing the rotation beyond 45°, the colors will again appear, becoming brightest at 90°, and fading away again to 135°. The second series of colors will, however, be complementary to the first; thus, for red we shall have green, for yellow, blue, and inversely.

The colored rings of polarization are best seen by means of the apparatus represented in *fig.* 73. This was invented by Soleil, and is well calculated for accurate measurements. Here there are three convex lenses, *b*, *c*, *d*, each one of about one inch focus; the two first, *b* and *c*, are separated by the sum of their foci, and in their common focus there is a plate of crystal, *l*, in a frame, turning on a horizontal axis: *a* is the polarizing mirror. Parallel rays falling upon and polarized by this mirror, pass through the lens *b*, converge towards the crystal, and strike the lens *c*: from this they emerge again, parallel, and striking the third lens, *d*, are again rendered convergent. A micrometer is placed between the lenses *c* and *d*; *t* is a tourmaline plate serving as a disperser.

i. Of the Chemical Action of Light.

The blackening of chloride of silver, caused by the action of light, was early suggested as one means of fixing the beautiful images of the Camera Lucida. Experiments on this subject failed, however, until recently, when the object was accomplished by Messrs. Niepce and Daguerre in France, and Fox Talbot in England. The former operators made use of a plate of copper, plated with silver, as the best surface to receive the impression of light. An exceedingly high polish is given to the silvered surface, which is then to be carefully cleaned and exposed to the vapor of iodine, until a deep golden yellow layer of iodide of silver has been formed. The plate is now ready to receive the impression. This is produced by means of a camera obscura of a construction especially adapted to the purpose. It consists of a square box, with a horizontal tube in the centre of one end, in which is placed a good achromatic lens of about ten inches focus; at the opposite extremity of the box there is a groove in which slides a plate of ground glass. The object whose image is to be transferred to the plate, is then to be brought before the camera, and its image, well defined and of the proper size, made to fall on the plate of ground glass. This is then to be removed and the prepared plate substituted, and allowed to remain for several seconds. On removing the plate no apparent effect will have been produced; the picture, however, has been made, although invisible. To bring it out, the plate is suspended in a dark box over a vessel of mercury, gently heated from beneath by a spirit lamp. The vapor of the mercury will slowly rise and adhere in the form of very minute globules to the parts of the picture acted on by light, the remaining portions not being affected.

To render this now visible picture permanent, the plate must be immersed in a weak solution of hyposulphite of soda, to dissolve such iodide of silver as has been unacted on by light. After gently washing the plate in water, and allowing it to dry, the operation will be completed. Instead of the silvered plate, paper may be employed as the medium, and various other substances used besides the salts of silver. The former process is called the *Daguerreotype ;* the latter the *Talbotype* or *Photograph.* This latter term is sometimes employed to denote all pictures produced by the chemical action of light.

Fig. 74, *pl.* 21, represents the form of the daguerreotype camera, as at present used ; *fig.* 75 is an enlarged view of the tube containing the achromatic objective. The mercury box for bringing out the image is seen in *fig.* 76. The best cameras are furnished by Voigtländer of Vienna, instruments of his construction being more used than any other, especially in the United States.

MAGNETISM AND ELECTRICITY.

A. Magnetism.

1. *On the Mutual Influence of Magnets on each other, and on Magnetic Bodies.*

A magnet is a body possessing the property of attracting and adhering to iron, and of being attracted by it. This attraction is termed magnetism or magnetic force, and its cause is generally considered to be a peculiar imponderable agency, conventionally termed the magnetic fluid. Magnets are divided into two kinds : natural, as in the magnetic oxide of iron (or loadstone), and artificial. Every magnet has on its surface a line or space where there is no attraction ; this is called the neutral line of the magnet. The two portions into which the magnet is divided by this line, are called its poles, although the poles are generally understood to indicate those two opposite extremities of the magnet where the attraction is strongest. If a magnet be dipped into iron filings, it will attract them to some points and not to others ; these points about which the filings accumulate are the poles. *Pl.* 20, *fig.* 1, represents this phenomenon for a natural, and *fig.* 2 for an artificial magnet ; in both *mm'* is the neutral line where there is no attraction. The intensity of attraction, as indicated by the quantity of the adherent filings, decreases from the poles to this central line. The experiment is best made by laying a piece of stiff paper on the extremities of a horse-shoe magnet ; on sifting fine filings upon the paper, over the poles, they will arrange themselves in regular curves, as seen in *fig.* 3, the influence of the magnet thus extending through the paper.

By suspending a bar magnet horizontally from a thread, and approximating a second magnet, it will be seen that each pole of the latter attracts one

pole of the former and repels the other. Thus, calling the two poles of the first magnet, n, s, and those of the second, n', s', then n' will attract s and repel n, while s' will attract n and repel s. And, in general, the like or corresponding poles of any two magnets will repel, while the unlike will attract each other. The two poles of the same magnet are therefore said to be unlike or opposite. Instead, then, of one magnetic fluid, the existence of two may be conveniently assumed, one acting at each pole.

Iron, under the influence of a magnet, itself becomes magnetic, possessing a like power of attraction, as is seen in the case of iron filings in the experiments previously adduced. If a small cylindrical rod of iron be appended to a magnet (*fig.* 4), it will be found to have acquired the same power of attracting iron filings, and throwing them into the magnetic curves. By a slight variation of the experiment (*fig.* 5) it may be shown that the contact of the magnet is not necessary to impart a temporary magnetic power to the iron. Here mm' will be the neutral line.

Steel possesses the same properties, in respect to the magnet, as iron, resisting its influence, however, more strenuously. By continuing the approximation for a long time, or by stroking the steel with the magnet, the former becomes permanently magnetic. Soft iron then differs from steel, in acquiring magnetism very readily, and losing it almost entirely when removed from the exciting cause; steel, on the other hand, is slow in acquiring magnetism, but retains it for a long time. The property by which a magnet developes magnetism in a piece of iron or steel is called *magnetic induction.*

Hardened steel is used almost exclusively in the construction of artificial magnets, which are known from their shape, as *magnetic needles*, *bar magnets*, and *horse-shoe* magnets. A magnetic needle consists generally of a lozenge-shaped bar (*fig.* 6), with its centre, c, resting on a fine pivot. In the best needles this centre is of agate. The magnetic needle is sometimes suspended by a fine thread.

Some magnets have three, or even more poles, as may be shown by laying a piece of paper on them, and sifting iron-filings upon the paper. The centres of attraction will indicate the various poles (*fig.* 7).

All bodies, in their relations to magnetism, may be divided into three classes: *magnetic*, or those which are attracted by both poles; *indifferent*, those on which no action whatever is exerted by the magnet; and *diamagnetic*, those which are repelled by both poles. The existence of this latter property was first discovered by Faraday. The bodies exhibiting it are bismuth, antimony, zinc, tin, &c. Iron, nickel, and cobalt, are examples of magnetic bodies; and ether, alcohol, and gold, of indifferent.

2. *Of the Magnetic Action of the Earth.*

A magnetic needle, suspended horizontally to a silk thread, or sustained on a pivot, exhibits a tendency, if left to itself, to take up a definite position

with regard to the horizon. One extremity or pole will be found to point nearly in the direction of the north pole of the heavens or earth, and the other pole towards the south. The extremities of the magnet are hence called the north and south poles, from their pointing in this manner. Some authors, however, call that the north pole of the magnet, which points to the south pole of the earth, and the one pointing to the north pole of the earth, the south pole.

The magnetic meridian of a place, or the line of direction of the magnetic needle, will generally be found to deviate somewhat from the true meridian. The angular value of this deviation is called the *variation* or *declination of the compass*. It is termed east or west as the north pole of the compass deviates east or west from the meridian. In *fig.* 9, *bc* represents the astronomical meridian of a place, and *sn* the magnetic meridian. The variation here is west. This variation differs not only in different places, but in the same place at different times. At the present time it is western in all Europe, and in northern Germany amounts to about 18°. The variation at New York city was found by Professor Renwick in 1837 to amount to 5° 28′ west. In some localities there is no variation, or the magnetic and astronomical meridians coincide.

An instrument for indicating the magnetic meridian, as also the variation of the needle, is called a *compass* (*pl.* 20, *fig.* 8). The pivot on which the needle is suspended is erected in the centre of a horizontal circle, whose circumference is graduated to 360°. The north and south line passes through 0° and 180°. To determine the variation a telescope is attached to the side of the compass box, with its axis parallel to the north and south line. By sighting the telescope in the astronomical meridian, the deviation of the needle from the north and south line of the compass will indicate the variation.

When a magnetic needle is suspended carefully by its centre of gravity, its position assumed in the magnetic meridian is not parallel to the horizon, but inclined to it. This position is called the *inclination* or dip of the needle, and varies in different latitudes. In the northern hemisphere it is the north pole that is depressed, the south pole dipping in the southern. A needle constructed to show the amount of this inclination is called a *dipping needle*. Here (*fig.* 10) the needle is placed on a horizontal axis in the centre of a graduated vertical circle. By placing the plane of the circle in that of the magnetic meridian, the inclination of the needle as read off on the graduated circle will show the dip. This inclination varies at different times for the same place, and is greater as we approach the poles of the earth. Near the terrestrial equator this needle will be horizontal, and an irregular curve connecting those places near the equator where the needle is horizontal, is called the *magnetic equator*. This curve encompasses the earth, at no point being more than fourteen degrees from the terrestrial equator. On each hemisphere, and near the true poles, there is one point where the dipping needle stands vertically: these two points are called the *magnetic poles* of the earth.

The greatest separation (14° S.) of the magnetic from the true equator

takes place about 28° west of Paris; at 120° west of Paris it reaches the true equator, turns then again towards the south, and at 160° west of Paris attains a south deviation of 3° 57′. At 174° west longitude, both equators intersect, the magnetic crossing into the northern hemisphere, but returning again to intersect the terrestrial equator at 18° east of Paris. At 62° east of Paris, the magnetic equator has a north latitude of 11° 47′; at 150° east, of 7° 44′; and at 130° east of Paris, of 8° 57′.

From the preceding phenomena it follows that the earth itself acts as a magnet, or possesses magnetism, although it is impossible to say exactly in what this magnetism consists, or where the centres of the magnetic influence lie. The total action exerted by the earth upon a magnetic needle is, however, not *attractive*, but simply *directive*. Thus a magnetized delicate needle laid carefully upon water, does not move towards the north, but only takes up a position in the magnetic meridian. This is because the distance between the poles of the needle is so infinitely short, compared with the distance of the needle from the magnetic pole, that while one pole of the needle is attracted, the other is repelled by precisely the same amount. As a consequence, the needle cannot advance, but must take up a position, the resultant of these two equal and opposite forces. This condition is illustrated by *fig.* 11.

Every declination needle oscillates continually, if unimpeded, describing arcs of variable extent. These oscillations are termed the *daily variation* of the compass, being greater some days than others. The limits are from half a degree to five or six minutes. The variations of the dipping needle are less conspicuous. For further information as to the several variations and occasional phenomena of the magnetic needle, we refer our readers to the section on meteorology.

The different durations of oscillation of a magnetic needle, before coming to rest, in different places, show a difference in the intensity of the magnetic force of the earth. The quicker the oscillation of the needle, the greater is the intensity of the terrestrial magnetism, the intensities of terrestrial magnetism being as the square of the number of oscillations made in an equal period of time. The *intensity compass* of Gambay is intended for experiments on the oscillations of the declination needle. It is shown in section by *fig.* 12, and consists of a circular box of wood, covered above by a glass plate, and containing two opposite apertures in the sides. The telescope, *l*, serves to observe through the apertures the oscillations of the needle, suspended from the thread, which passes through the upright column.

The laws of magnetism have been recently investigated by Messrs. Gauss and Wilhelm Weber. In his experiments on the action of magnets, Weber made use, among other apparatus, of a common compass, a magnet for deflecting the needle of the former, and a scale. In one series of experiments, the scale is laid perpendicularly to the magnetic meridian (*pl.* 22, *fig.* 50) as also the magnet, *ns*, lying upon the extremity of the scale. In the second series, the scale was laid in the direction of the magnetic meridian and the deflecting magnet at right angles to it

(*fig.* 51). The apparatus is especially calculated for being used by travellers; its application will be readily seen by an examination of the figures.

A rod of soft iron, about eighteen inches long, fixed in the direction of the dipping needle for a certain length of time, will become magnetic; rods even placed for a great length of time at other directions with the horizon, will exhibit feeble traces of magnetism. Thus the vertical gratings of buildings are almost always magnetic. Magnetism may be fixed in such bars of iron by a few blows of a hammer.

The intensity of a magnet may be measured by suspending weights to the armature until this is torn from the magnet. The results thus obtained are, however, not very satisfactory, as a magnet can be greatly strengthened by gradually adding weights, not enough at any one time, however, to produce the above-mentioned separation. It is a little singular that such a separation of the armature should result in a considerable weakening of the magnet. We are indebted to Coulomb for the first indication of a more accurate method of determining the intensity of a magnet. For this purpose he first employed the oscillations of a magnet, viewing the needle oscillating under the influence of terrestrial magnetism, as a compound pendulum, and considering that the operating force depended upon the intensity of terrestrial magnetism and the magnetic condition of the needle. From his experiments he found that the magnetic forces are inversely as the squares of the times of oscillation, and that the times of oscillation are inversely as the number of oscillations in a given time.

The second method employed by Coulomb consisted in the use of his *torsion balance*, an apparatus in which a vertical metal thread, stretched by an appended weight, and experiencing a torsion, endeavors to return to its original position when left to itself, the force with which this takes place being proportional to the torsion. The instrument employed by Coulomb is represented in *figs.* 13 and 14, *pl.* 20.

A metal thread, wound at its upper end around a horizontal axis, supported by two small posts, p and p', hangs in a vertical cylinder, covered above by a circular disk, ss', perforated in the centre. A second disk, mm', turns centrally in a groove on the first disk with a slight degree of friction. The disk ss' is graduated on its circumference to degrees, and an index on mm' serves to read off the amount of rotation. The wire carries at its lower extremity a small brass stirrup, in which may be placed the needle or bar whose magnetic force is to be ascertained. First of all an unmagnetized needle is to be laid on the stirrup, and the disk mm' turned until the needle lies exactly in the magnetic meridian; a magnetized needle is then to be substituted for it, and this will be retained in the same position, partly by the terrestrial magnetism, partly by the untwisted threads. If now the disk mm' be turned by a certain angle, the needle will be affected on the one hand by magnetic force, and on the other by the torsion of the thread; it will consequently take up an intermediate position, depending on the ratio of the two forces, and from which this ratio may be determined.

Coulomb has also the credit of determining the law, according to which the strength of the magnetism in a magnetic bar decreases from the extremity to the neutral line. The results of his observations are shown graphically in *fig.* 15, *pl.* 20. Here *om* represents the half of a magnetic bar, *m* being the neutral line and *o* the extremity; the perpendiculars erected at different points along *om* exhibit, according to a given unit, the observed intensity of magnetism at these places. As is evident from the figure, the intensity is greatest at the extremity *o*, diminishes towards the middle, very rapidly at first, and finally disappears entirely at or near the neutral line.

3. *On the Method of Preparing Artificial Magnets.*

Steel may be magnetized or rendered magnetic in various ways; of these the following are best known and most convenient in practice: 1. *The method of Duhamel*, or *the separate touch*. This consists (*fig.* 17) in so placing two powerful bundles of magnets (*fig.* 16), with their opposite poles, *f* and *f'*, towards each other, that their axes fall in the same straight line. The bar or needle to be magnetized is laid on the poles of the two bundles of magnets, and supported in the middle by a piece of wood. The two touching magnets, *g* and *g'*, are taken, one in each hand, and held at an angle of 25°—30°, with their opposite poles nearly in contact, and resting on the middle of the bar. They are then to be separated, being drawn along to the opposite extremities of the bar, which are to be reached simultaneously. They are then brought back again, and the operation repeated until the magnetization is completed. It will be understood that the touching and stationary magnets must have their poles directed the same way.

The method of Duhamel is best calculated for magnetizing fine needles, such as those required for compasses. For thicker bars, as from one to two lines in diameter, *the method of Œpinus*, or the *double touch*, is much preferable. Here (*fig.* 18) the bar is placed as before, and the other conditions are nearly the same, except that the touching magnets are held at a more acute angle, and instead of being separated they are kept nearly in contact, the stroking extending alternately from one extremity of the bar to the other. The contiguous extremities of these magnets must be kept from actual contact by a small piece of wood, *l* (*fig.* 18). After the operation has been continued for a sufficiently long time, the magnets are to be brought back to the middle of the bar and raised up. The strength of the magnetism communicated to the bar depends upon that of the touching magnets; there is a point of saturation, however, beyond which there is no increase in intensity. The intensity of a strong magnet is often considerably impaired when brought in contact with a weaker one.

The most powerful artificial magnets are unquestionably those composed of perfectly hardened steel; they are, however, besides a liability to fracture on account of their brittleness, very apt to have more than two poles

developed in them. For this reason tempered steel is generally employed, although furnishing weaker magnets.

The magnetic force is completely destroyed by great heat, and cannot again be restored in natural magnets. In artificial magnets this may be done by again hardening the steel. The limit of temperature beyond which bodies are unsusceptible of the influence of the magnet, varies with the material. This, for manganese, lies between 65° and 70° F., for nickel at about 662° F., and for cobalt far above a white heat.

Light possesses the power of magnetizing a steel needle. This property is nearly confined to the violet ray, being slightly shared, however, by the blue and green. Only that half of the needle which is to become the north pole must be exposed to the influence of the ray, it being necessary carefully to cover the other. A needle will even be magnetized by laying a plate of glass, colored blue or green with cobalt, over the north pole, and exposing the whole to the solar rays. The same end will also be accomplished by wrapping the north pole with blue or green bands, and placing the whole for some days in the sun.

An *armature* is necessary to retain the magnetism of an artificial magnet for any length of time. This is a piece or plate of soft iron, so constructed as to connect the poles of the magnet, thus becoming not only magnetic itself, but reciprocally causing the development of fresh magnetism in the magnet. In *fig.* 19, *pp'* represents the armature of a horse-shoe magnet. The ring *nn'* serves to suspend the magnet. The armature of natural magnets is exhibited in *figs.* 20, 21. Here *ll'* are the wings, *pp'* the feet of the armature; the former are nearly as broad as the magnet, and about one line thick.

A *magnetic* battery, required whenever a great degree of magnetism is wanted, is formed by the combination of a number of single magnets with their like poles placed together. *Fig.* 19 is a horse-shoe battery; the one represented in *fig.* 16 is the form recommended by Coulomb. This consists of twelve bars, disposed in three layers of four bars each. The bars of the central layer are from two and a half to three inches longer than the others, which are of equal length. The bars are all fastened in pieces of iron, *f*, which serve both for armatures and feet to the compound magnet. The whole apparatus is held compactly together by the brass bands *cc'*.

B. Electricity.

1. *Of Electrical Actions.*

Many bodies, as glass, resin, sulphur, amber, &c., exhibit the property of attracting light objects on being rubbed. If the friction be sufficiently violent, and the proper rubber be used, a spark will pass from one of these substances to the knuckle. The cause of these curious phenomena is assumed to lie in the existence of a peculiar fluid or fluids called electricity, pervading all bodies.

An apparatus for showing whether a body possesses electrical properties is called an *electroscope* or *electrometer*. The simplest of these is the *electrical pendulum* (*pl.* 20, *fig.* 22), consisting of a small ball of elder pith, suspended by a silk thread. If a body, when properly excited, attract this ball, the presence of free electricity in the former may be inferred, the want of such attraction being an evidence of its absence. The *electric needle*, another electroscope, constructed somewhat like the magnetic needle, consists of a light straw, supported on a pivot, and having pith balls at the extremities. This is quite sensitive in its indications, as is also *Coulomb's electroscope*, represented in *fig.* 23. Here *gg'* is a light rod of shellac, with a gilded pith ball or slip of gold leaf, *e*, at one extremity, and suspended by a vertical filament of silk, fine wire, or glass hair. The upper end of the latter is wound around a horizontal beam, *t*, by whose rotation the thread may be elevated or depressed. A cylinder of glass, *vv'*, inclosing the bar and protecting it from the air, carries a graduated circle, *dd'*, and is covered above by a top, *cc'*; an opening in the latter admits of the gradual introduction of the body to be tested. If it contain free electricity, then the extremity, *e*, will be first attracted and then repelled.

All bodies were formerly divided into two classes, those which became electrical by friction, and those which did not; the former were called *idio-electric*, the latter *anelectric*. It was subsequently ascertained that all bodies exhibited electrical properties to a greater or less degree when rubbed, differing, however, in the readiness with which electricity was received and propagated. The former were called *conductors*, the latter *non-conductors* or *insulators*; terms nearly synonymous with anelectrics and idio-electrics. The division into good and bad conductors would be a much better one, since there is no body incapable of conducting electricity to a certain extent. Water and liquids in general, animal bodies, and above all metals, are good conductors. A conductor can only remain electric as long as it is surrounded by bad conductors or is insulated.

The poorest conductors are silk, glass, resin, dry air, &c. To determine the electricity of an insulated conductor, attach to it two pith balls, by means of a conducting thread. These will diverge from each other whenever the body from which they are suspended is electrified, the divergence being in proportion to the amount of charge in the conductor. Two strips of gold leaf suspended together at one end, and with their surfaces in apposition, form a very delicate electroscope. They are generally inclosed in a cylinder of glass to protect them from aerial currents. An arrangement of this kind is found in the *gold leaf electrometer* of Bennett. Here the leaves are held by one extremity in the lower end of a rod of brass, let into the cover of the glass vessel, and carrying a screw at the upper end for attaching a brass ball or plate. To insulate the leaves completely, the rod is wrapped in two places with silk, and inclosed in a glass tube, which is then coated externally and internally with shellac. (See *pl* 22, *fig.* 65.)

The *straw electrometer* of Volta (*pl.* 20, *fig.* 26), and the *gold leaf electrometer* (*pl.* 22, *fig.* 61), are exceedingly sensitive, besides serving to

measure the intensity of the electricity by the divergence of the bits of straw or gold leaf. This divergence is measured along a graduated arc attached to the glass cover. In the best of these instruments a drawer, sliding into the bottom, contains chloride of lime, for the purpose of keeping the inclosed air perfectly dry.

Electricity is confined to the surface of bodies, penetrating below to an entirely inappreciable extent. This is shown by the following experiment:—Electrify an insulated metallic ball (*pl.* 22, *fig.* 60), and fit to it two hollow metallic hemispheres with glass handles. Suddenly removing these hemispheres, they will be found to contain all the electricity, all traces having vanished from the ball.

If an electric pendulum or pith ball electroscope (*pl.* 20, *fig.* 22) be brought near an excited glass tube or rod of sealing wax, the pith ball of the former will first be attracted to the tube, and after contact immediately repelled, this repulsion continuing until the ball is touched by some conductor. Hence we conclude that electrified and unelectrified bodies attract each other. This attraction and repulsion are well illustrated in the *electric dance* (*pl.* 22, *fig.* 72). Here two metallic plates are required one suspended from the prime conductor of an electric machine by a brass chain, the other supported on a conducting stand at a short distance immediately below the first. Little figures, made of elder pith or paper, are then to be placed on the lower plate. When the upper plate is electrified the figures will be attracted to it, and receiving a portion of free electricity, will be immediately repelled to and attracted by the lower plate. Here giving off their free electricity, they are again in a condition to be attracted by the upper plate, and the dance can thus be maintained for any length of time.

If we take two pith ball electroscopes (*pl.* 20, *fig.* 24), and electrify one from an excited glass tube, and the other from sealing-wax, instead of repelling each other, as would have been the case if both had received electricity from either the glass or the sealing-wax, an actual and mutual attraction will ensue. For this reason we are entitled to assume a difference in the electricity of glass and resin, and consequently the existence of two kinds of electricity. These have been named, respectively, *vitreous* and *resinous*, or *positive* (+) and negative (—). For some time the theory of Franklin, that there was but one kind of electricity, an excess of which was equivalent to the vitreous, and a deficiency to the resinous electricity, was preferred by scientific men to that which assumed the existence of two distinct fluids. This latter theory, that of Dufay, as modified by Symmer, is now more generally adopted than the other. According to this theory the fluids are combined in the ordinary condition of a body. If, however, the body be rubbed by the proper substances, this equilibrium is disturbed, one of the fluids passing into the rubber, the other remaining in the original body. Rubber and rubbed will always then be in opposite conditions of electricity, the same body with different rubbers being capable of presenting successively the phenomena of either fluid.

Free electricity can pass from one body to another, provided the latter be a conductor, in two ways: by immediate contact, and by transmission at a greater distance. In the latter case a spark will be observed to pass between the two bodies at the moment of intercommunication. This spark, which, under favorable circumstances, may be two feet in length, is capable of inflaming alcohol, ether, resin, gunpowder, gun-cotton, &c., as well as the inflammable gases. The latter experiment is readily performed by means of the *electric pistol* (*pl.* 20, *fig.* 25), which consists of a small metallic vessel, closed by a cork stopper, and filled with an explosive mixture, as of oxygen and hydrogen. Into the lower part of the tube a glass tube, *tt*, is cemented, and into this is again cemented by sealing-wax, a metallic wire ending in two small balls, *b*, *b'*. When the electrical spark is communicated to the outer ball, it passes from the other ball to the opposite wall of the vessel, inflaming the gas in its passage; by the resulting explosion the cork is driven out with a loud report. The *electrical mortar* (*pl.* 20, *fig.* 39) acts somewhat differently. Here the electricity produces so sudden an expansion in gas or liquid, oil for instance, as to eject a ball with great violence. The amount of this expansion may be measured by the so-called *thermometer* of Kinnersley (*pl.* 20, *fig.* 40). In its lower part there is a liquid which at first stands at an equal height in two intercommunicating tubes. The expansion of the gas above the liquid in the larger tube, where a spark passes through between the balls, *b*, *b'*, causes its ascent in the smaller tube, *tt'*.

2. *On Electrical Induction; the Electric Machine; the Electrophorus.*

When an unelectrified body is brought near one that is electrified, a separation of the combined electricities of the former takes place, the positive occupying one extremity, and the negative the other. The electricity of the second body attracts the opposite kind to its end, repelling that of like character with itself to the other end. When the bodies are again separated, the decomposed electricities unite, and no sensible trace whatever of free electricity remains. This decomposition of electricity in one body by another, without actual contact, is said to be produced by *electrical induction.*

To illustrate the preceding proposition, we may make use of the following experiment (*pl.* 22, *fig.* 63). Take a rod of metal with its extremities bent into hooks, and fix it horizontally on an insulating vertical stand of glass. To each hook suspend two pith balls with strings of some conducting material, as linen. Approximate an electrified body, *r*, to the metal rod, and both pairs of pendulums will diverge, showing that they have become electric. They collapse, however, on the removal of *r*. The electricity found to exist in the balls is the result of the induction of the body *r*.

To determine the kind of electricity in any body, whether positive or negative, it is necessary to make use of an electroscope charged with a

known kind of electricity. This is done by bringing a body, *r* (*pl.* 22, *fig.* 62), of known electrical condition near the top of an electroscope, and then touching this top with the finger. The induction of the body, *r*, drives into the finger the electricity of like character with its own, the electroscope retaining the opposite electricity on the removal of *r*. The leaves or straws of the electroscope will, however, still be divergent. If, for instance, the body first approximated had been a glass tube excited by silk, then, its electricity being positive, that of the electroscope would be negative. Now, if on approaching a second electrified body, the leaves were still to remain divergent, it would be an evidence that the second kind of electricity was of the same character with that already in the gold leaves, negative in our illustration. An approximation or entire collapse of the leaves would follow on bringing near them the opposite electricity, positive in our instance. Connecting two perfectly similar electroscopes (*pl.* 22, *fig.* 64) by an insulated conductor, and bringing an electrified body, *r*, near one of them, the balls or leaves will diverge in both. Removing first the conductor, and afterwards *r*, the leaves in both electroscopes will remain divergent, indicating the presence of free electricity. This, however, will be positive in the one and negative in the other.

The *electric machine* consists of three elementary portions, a rubber, an idio-electric, and an insulated prime conductor. The idio-electric generally consists of a circular plate of glass, or a glass cylinder, whence the distinction into plate and cylinder machines. The rubber is generally a cushion stuffed with horse-hair, having anteriorly a rubbing surface of leather coated with amalgam. The prime conductor is most generally one or more hollow cylinders of tin or brass, with hemispherical terminations, and insulated by glass feet. *Pl.* 20, *fig.* 32, represents a *cylinder machine* according to Nairne's construction. Here *a* is the glass cylinder, turned about a horizontal axis, *b*, by means of a handle, and rubbed along its whole extent by a single cushion. The latter is connected with the conductor, *r*, while a second conductor, *v*, is placed on the opposite side of the cylinder, to which it presents a row of fine sharp points. A flap of oiled silk attached to the rubber, reaches over the cylinder nearly to these points, to prevent any escape of electricity from the excited glass. In turning the cylinder, it and the conductor *v* are positively electrified; the rubber and conductor *r* negatively. The entire apparatus must be well insulated by legs of glass. To obtain positive electricity the negative conductor must communicate with the earth, or some large body of conducting matter, while the positive conductor remains insulated. To obtain a negative fluid, the conditions as to the insulation of the conductors must be reversed.

Fig. 29, *pl.* 20, represents a plate machine. The glass disk, *a*, is perforated in the centre, and through the aperture there passes a horizontal axis, turned by the handle *bm*. The two posts, *d*, sustain both the plate and the rubber, the latter consisting of two pairs of cushions, which reach from the edge of the disk to over about the fourth or sixth part of the diameter. The prime conductor, *fgf*, is insulated by the glass pillars, *h*, and ends in two arms, *i*, embracing the plate horizontally. *Figs.* 30 and 30^a represent more clearly

the arrangement of the rubbers. Here also the plate is partly covered by pieces of oiled silk to prevent the escape of electricity. The most powerful plate machines now constructed consist of two disks on the same axis, each with its set of rubbers.

The great plate machine of Van Marum (*pl.* 20, *fig.* 31) is distinguished from the preceding by admitting the collection of either positive or negative electricity. The two rubbers are placed at the extremity of the horizontal diameter of the disk, and are attached to two wooden globes, sustained on glass posts. AB and CD are two movable metal arcs, their planes at right angles to each other.

To determine the degree to which the prime conductor is charged, we make use of the *quadrant electrometer* of Henley (*pl.* 22, *fig.* 59). Its construction will be evident from an inspection of the figure. The greater the charge of the conductor, the greater will be the ascent of the cork ball, this being repelled from the electrified foot of the electrometer. A graduated semicircle indicates the angle of divergence.

The *electrophorus* (*pl.* 20, *fig.* 27) in many instances may advantageously replace the electric machine. It consists of a cake of resin, sealing-wax, or mixture of shellac and Venetian turpentine, poured into a shallow disk, or upon a metal plate. The surface must be as smooth and polished as possible. The latter is electrified negatively by rubbing with a fox's tail or cat's skin. A plate of metal, somewhat less in diameter than the cake of resin, and provided with a glass handle, is now to be laid upon it. The negative electricity of the lower cake decomposes the combined electricity of the upper, attracting its positive and repelling its negative fluid. On touching the upper surface of the metal plate with the finger, this negative electricity passes off, and on lifting the plate by its glass handle, it will be found to be charged positively. It will now give off a spark, a succession of which may readily be obtained, without further excitation, by touching the plate with the finger, replacing it as before, and thus continuing the operation. *Fig.* 28 is an enlarged representation of the edges of the plate.

It has been ascertained quite recently that a jet of steam, escaping from a narrow aperture, is electrified positively, and upon this fact has been founded the construction of the *hydro-electric machine* (*pl.* 22, *figs.* 73–75). This consists, in the arrangement of Eisenlohr, of a boiler supported on four glass legs. *Fig.* 75 is a section of the boiler, showing the method of heating the water. Upon the middle of the boiler is placed a cap, in which is screwed a short brass tube, which can be closed by a cock. Upon the latter the escape apertures are screwed, as shown in *fig.* 74. There are six horizontal tubes passing through a tin box, filled with cold water, which serves to condense a part of the escaping steam. When the steam is of sufficient tension it is made to escape with great violence by turning the cock (*fig.* 73) a quarter round. On account of the friction of the steam against the sides of the escape pipes, the two become oppositely electrified. To obtain the most intense action of the machine, it is necessary to draw off the electricity of the steam, which is done by

receiving it on a series of metal points, placed in the current of steam, and connected with the floor by a conductor.

3. *Of Combined or Disguised Electricity.*

When two conductors, charged with opposite electricities, are separated by a tolerably thin layer of air, the two fluids mutually attract and retain each other, so that neither gives evidence of its presence by any specific action, and either may be brought into contact with a conductor without passing off through it. The two opposite fluids are then said to be combined, disguised, or paralysed. The mutual retention is more complete if some other insulator, as glass or resin, be used instead of air, which, on account of its rarity, cannot prevent the union of the two fluids by the passage of a spark. This separation by glass occurs in the *Franklin plate* (*pl.* 20, *fig.* 33). By this is to be understood a plate or pane of glass, coated on both sides with tin foil to within a few inches of the edge. If now one side be charged with positive and the other with negative electricity, the two fluids will exert a powerful attraction on each other. For this purpose it is only necessary to bring one coating in contact with the prime conductor of an electric machine, and to connect the other coating with the earth. Turning the machine the electricity of the glass cylinder or plate becomes decomposed, the positive remaining, the negative passing off to the rubber, and thence along the connecting chain to the ground. The positive fluid of the glass then decomposes the electricity of the prime conductor, attracting the negative, which, mixing with the positive on the glass, restores the equilibrium; this, however, is immediately disturbed again by the continued friction of the rubber. The same operation now takes place between the positively electrified prime conductor and any body with which it is in contact, the Franklin pane for instance. The negative electricity is attracted to the positive of the conductor; the one side then of the pane is charged with the positive fluid. This acts by induction on the combined fluid of the opposite coating, and drives off its positive electricity through the conducting medium into the ground, retaining the negative. The two sides will thus be oppositely electrified. But, although the two fluids thus mutually retain each other, one or the other will always be in excess, which will be drawn off by touching with the finger or other conductor. The other side will then possess a surplus which may also be drawn off in the same manner; and thus by applying the conductor a great many times alternately to the two sides of the pane, it may gradually be deprived of all its free electricity. The same restoration to equilibrium might have been effected by the instantaneous combination of the two fluids through a *discharging rod* (*pl.* 20, *fig.* 34). This consists of two jointed arms of brass, *bc*, *cb'*, with a glass handle, *m*, *m'*, to each arm, as in the figure, or else a single glass handle placed at the joint. The arms are tipped with balls which may be approximated or separated by the motion of the arms on the hinge-joint at

c. If one side of the Franklin pane be touched by one ball, and the other ball be made to touch the other side, there will be an instantaneous exchange of electricities along the brass arms. The glass handles serve as a measure of precaution in preventing any shock, either direct or by induction, to the individual performing the experiment.

The *Leyden jar* (*pl.* 20, *figs.* 35, 36) acts on the same principle with the Franklin plate. It consists of a cylindrical glass vessel, open above, and coated on the bottom and sides of both surfaces with tin foil, to within a short distance of the top. Into the top a wooden cover, *gg'*, is made to fit accurately. Through the cover passes a brass rod, pointed above with a ball, *b*, to screw on over this point; from the lower end hangs a fine chain, the extremity of which rests on the tin foil coating on the inside of the jar. The wooden cover and the uncovered sides should be coated with lac or sealing-wax varnish. Instead of the inner coating of tin foil, iron filings, shot, salt water, or any other conductor, may be used; the tin foil coating is, however, much the most convenient. The jar is charged by connecting the knob with the prime conductor, and the outer coating with the earth, which latter is the case when the jar is set on an uninsulated table. Here the induction is the same as in the Franklin pane; the negative electricity passes from the inside of the jar to the prime conductor, the positive fluid which remains decomposes the electricity of the outside, driving off the positive into the earth. The two sides are then charged with the opposite fluids, the inside positive, the outside negative. These conditions will be reversed by connecting the outside of the jar with the prime conductor, and the inside with the earth. The Leyden jar may also be charged by the electrophorus; whenever all or the greatest part of the combined electricity of a jar is decomposed in this manner, it is said to be *charged*. It may then be *discharged* by means of the discharging rod, by resting one knob of the rod on that of the jar, and bringing the other in communication with the outside.

When powerful electrical results are required, it becomes necessary to use either very large jars or else a number of jars combined in an *electrical battery* (*pl.* 20, *fig.* 37). Here all the outside coatings must be connected by resting on a conductor, and all the inside by means of rods.

The *universal discharger* of Henley (*pl.* 20, *fig.* 38) is a very useful instrument for directing the charge of batteries and jars in particular directions. It consists of two metallic rods, ending in points, coverable by balls, *d, f;* the rods are insulated by glass pillars. The other extremities of the rods carry rings or hooks. There is an insulated table, *df*, between the two posts. To cause the charge of a jar to pass through a given object, it is to be placed on an insulated table, and the discharging rods adjusted to the proper length. A chain is brought from one rod to the outside of the jar, and by means of a glass handle attached to the ball, which tips the chain hung to the other rod, a communication is made with the inside of the jar. The interchange of positive and negative electricity from the two coatings must pass along the wires, and consequently through the

interposed body on the table, thus forming the circuit. To melt or heat a fine wire, it is made to form part of the circuit in connecting the two rods. In the same manner and with this instrument wood and paper may be perforated; resin, alcohol, ether, &c., inflamed, &c., &c. The action of the electric spark in the discharge of a Leyden jar is much more powerful than that from a prime conductor. By the term *striking distance* is understood the space through which the discharge spark passes in the discharging; it is the measure of the charge in the jar, since the striking distance of a jar is proportional to the density of the electricity accumulated in it.

The electricity of a Leyden jar penetrates to a slight distance below the surface into the glass, as may readily be shown by experiments on a jar with movable coatings (*pl.* 20, *fig.* 41). Charge as usual, remove the coatings, and replace these by fresh ones. On applying the discharging rod, the jar will be found to be charged nearly as high as if communication had been made between the original coatings. This experiment shows conclusively that the charge resides in the glass, the metallic coatings serving only to limit the inductive action. As a further proof of this, it is found that after a large jar has been discharged, a second and feebler discharge may be obtained after a short time, the interval being necessary to allow the residuary electricity in the glass to pass to its surface.

The action of the *condenser*, an apparatus for accumulating feeble electricity, depends for its principle upon electrical induction. This consists essentially of a gold leaf electrometer (*pl.* 20, *fig.* 26), with the upper plate covered with a thin layer of varnish. Upon this is laid a second plate similarly coated and provided with a glass handle. Call the upper plate A and the lower B. If a conductor charged with a very feeble degree of electricity be brought in contact with B, a portion of the fluid will be given off, and this will cause the decomposition of that in A. Touch A with the finger, and the electricity similar to that of B will be given off. The electricity remaining being now of the opposite kind, exerts such an attraction on the electricity in B as to permit this to receive an additional charge. In this way an accumulation may take place in B, which will be shown by the divergence of the leaves on removing the upper plate.

4. *Of Electrical Light and the Motions of Electrified Bodies.*

Electrical light is visible only when electricity is in motion, or the equilibrium of the fluids is disturbed. The greatest accumulation of electricity, under other conditions than these, is unaccompanied by the phenomenon. Electricity passes off spontaneously from the angles and points of electrified bodies, the appearance of the accompanying light varying with the kind of fluid. A current of positive electricity from a point exhibits the form of a brush (*pl.* 20, *fig.* 44); negative electricity

appearing under the same conditions in the form of a simple star or luminous point.

Various interesting experiments may be performed by interrupting the continuity of a conductor, thereby causing the electricity to leap through a non-conductor, as air, and thus exhibit itself in the form of a spark. The first of these here to be mentioned is the *lightning plate* (*pl.* 20, *fig.* 42). This consists of a pane of glass, with strips of tin foil pasted upon it, as in the figure, so as to form a continuous communication between *a* and *z*. The tin foil is then cut through, or pieces cut out of it, the cuts representing letters, figures, &c. At each point where the continuity is thus interrupted, a spark will be visible on passing the charge of a Leyden jar from *z* to *a*. *Lightning tubes* are constructed on the same principle, except that small lozenge-shaped pieces of tin foil (*fig.* 43) are pasted on tubes passing spirally round in a continuous line. Holding one end of this tube to the prime conductor of a machine in active operation, a constant series of sparks will be observed, answering to the points of the several lozenges of foil.

Not the least interesting phenomena of electrical light are those presented by its passage through a total or partial vacuum. For this purpose we may use a straight tube of an inch or two in diameter, or an ellipsoidal glass vessel, as in *pl.* 22, *fig.* 71. This has metal caps at each end, one of them provided with a stop-cock and screw, for attachment to an air-pump, the other with a stuffing-box, through which slides a brass wire terminated by a ball. There is also a ball projecting inside from the opposite cap. On exhausting the air, and bringing one of the brass caps into contact with an excited prime conductor, and the other with the earth, a diffused violet or purplish light will be found to pervade the tube, passing from one ball to the other. If some air be admitted, the light will be in the form of purplish arcs. Similar phenomena occur in the Torricellian vacuum.

Experiments have been instituted by Wheatstone, with the assistance of a mirror rotating on a vertical or a horizontal axis, to determine the duration of the electric spark, as also the velocity with which electricity is transmitted along conductors. To ascertain this latter point he made use of the following arrangement:—Six balls, *a*, *b*, *c*, *d*, *e*, *f* (*pl.* 20, *fig.* 45), were attached in a horizontal line to a board about three and a half inches in diameter, called the spark board. A communication was established by a wire between *a* to the inner, and from *f* to the outer coating of a Leyden jar; *b* and *a*, *d* and *c*, *e* and *f*, were about one tenth of an inch apart; a coil of wire conducted from *b* to *c*, and another similar one from *d* to *e*. The length of each interval of winding between *b* and *c* and *d* and *e*, amounted to one fourth of a mile. When the inner and outer coatings of the Leyden jar were brought into communication by the simultaneous contact of the wires attached to *a* and *f*, three sparks would be transmitted: one between *a* and *b*; one between *c* and *d*; and one between *e* and *f*. At a distance of ten feet from the spark board, and at an equal height with it, the apparatus with the rotating mirror was attached, its axis of rotation horizontal and parallel to the line of the six balls. The observer is to be placed with the axis of rotation opposite to him, looking down from above

on the mirror, which must be inclined at an angle of 45°, when the balls and sparks are visible to him. During a rapid revolution of the mirrors, the sparks appear elongated, the middle ones somewhat displaced towards the external ones. From the amount of this displacement, the rapidity with which the mirror was rotated, &c., Wheatstone calculated that the electric current traversed 288,000 miles in a second, light moving at the rate of 192,000 miles in the same time.

Several interesting experiments may be performed by means of the current of air which sets off from a point discharging electricity. One of these is illustrated by *fig.* 76, *pl.* 20. A pointed rod, *cp*, is fixed in the top of a prime conductor, and upon its upper extremities is balanced a horizontal wire, *tt*, with the two points bent in opposite directions in a horizontal plane. The re-action of the air from the points causes a rapid rotation of the wire in an opposite direction. (By mistake of the Engraver two figures are numbered 76. The one here referred to stands nearly in the centre of the plate.)

Electricity may be developed in other ways than by simple friction. Thus it may be produced by pressure, as by pressing a plate of metal with an insulating handle, on a piece of oiled silk; on removing it after a few minutes, the former will be negatively and the latter positively electrified. A slight pressure will develope it likewise in calcareous spar, topaz, fluor spar, &c., which will be sensible for several days. It is produced also by heat, as in the case of the tourmaline. Heat this mineral, and one end will become positively electrified and the other negatively, the same polar condition being presented in the fragments, just like the fragments of a single magnet. The limits of temperature between which this electricity is exhibited in the tourmaline are 50° and 300° F. On cooling a tourmaline thus treated, the electricity disappears for a time, then re-appears, but with inverted poles, and remains until the temperature sinks below 50° F.

C. Galvanism.

1. *Development of Electricity by Contact.*

Electricity may be developed, not only by friction and the other methods just mentioned, but also by the contact of different bodies. This kind of electricity has been called *Galvanism*, from its discoverer, Galvani of Bologna. It is exhibited, however, only in the case of very good conductors, metals for instance. If two different metals are connected by the nerves of certain muscles, sudden convulsions are produced in the latter when the two metals are brought into contact. This experiment was first performed by Galvani on the prepared legs of frogs, and the contortions were supposed to result from the existence of certain currents of an *animal* electricity. His countryman, Volta, first showed that it was common electricity which caused the phenomenon. *Pl.* 20, *fig.* 47, represents the experiment instituted by him, namely, a pair of frog's legs, connected

by an arc, one half zinc, the other copper. When the two metals are brought into contact, the legs assume the position shown by the dots in the figure. A proof of the correctness of Volta's theory of the phenomenon just mentioned, is furnished by an experiment with the condenser (*pl.* 20, *fig.* 26). If the upper plate be touched with the finger, and the lower with a piece of zinc, lead, tin, iron, &c., and the upper plate then removed, the gold leaves will diverge, and thus indicate an electricity developed by the metallic contact. The following experiment, also suggested by Volta, is still more satisfactory: Solder two different metals, as zinc and copper, together, as shown in *pl.* 20, *fig.* 48 (*ss'* being the place of junction), and taking the zinc in the hand, touch the lower plate of the condenser with the copper, applying the finger at the same time to the upper plate, and a divergence of the leaves will immediately ensue. When zinc and copper are in contact, the former becomes positively, the latter negatively electrified; and generally, if any two different metals are in contact, one will be positively electrified, and the other negatively. This may even be the case with the same metal in different states, as cast and rolled zinc. Metals and other bodies becoming electric by contact, form, in this respect, a series, called the scale of electric tension. This scale is as follows: manganese, carbon, platinum, gold, mercury, silver, copper, iron, tin, lead, zinc, &c. Any one of these will become electrified, negatively by contact with one following it in the series, and positively by contact with one preceding it. The electricity developed is more sensible as the two substances stand further apart in the scale. When three or more metals are laid one above the other, the electric tension of the terminal plates is the same as if the intervening ones were altogether absent.

2. *Of the Galvanic Circuit.*

When two different metals are connected by a liquid conductor, as salt or acidulated water, a galvanic or electric current will be established in the liquid. From one metal there passes a positive current, and from the other a negative, both meeting in the liquid. A combination of several series of elements succeeding each other in the same relative order, is called a compound galvanic series or battery. The arrangement recommended by Volta for generating galvanic electricity, and called the Voltaic pile, is as follows: a square or round plate of zinc is to be soldered to one similarly shaped of copper, a sufficient number of these pairs being provided to make the pile of the proper height. These are to be placed one above the other, the zinc element having the same relative position in all the pairs, and each pair being separated from the next by a disk of flannel soaked in acidulated or salt water. The order will then be copper, zinc, cloth, copper, zinc, cloth, &c. (*pl.* 22, *fig.* 69). *Pl.* 20, *fig.* 49, represents a pile of twenty pairs of plates, which are held in place by a frame of glass or wooden rods. That end of the pile towards which the zinc element of each pair is turned, is termed the positive pole, and the other the negative. When both poles are

insulated no free electricity is observable in the middle of the pile; it becomes evident in increasing intensity towards the extremities. If one pole be insulated, this alone exhibits free electricity. When both are connected, a galvanic current is produced.

The Voltaic pile, as just described, has now gone almost entirely out of use, being in many respects very inconvenient and unsuitable. In its stead, various other arrangements have been introduced, called cell, trough, cup, box, &c., batteries. In a *cup battery* each pair consists of a plate of zinc and copper, connected by a strip of metal. The moistened disks are replaced by cups filled with the conducting liquid, and disposed in a circle or straight line. Each cup contains the zinc element of one pair and the copper of the next. In the *trough apparatus* (*pl.* 20, *fig.* 52), instead of a series of cups there is a rectangular wooden trough, divided into separate divisions or cells by transverse partitions.

Wollaston's battery, which is shown in *pl.* 20, *fig.* 54, from the front, and *fig.* 55, in ground plan, is an illustration of the cup apparatus; *fig.* 53 is a side view of two pairs of plates. Each vessel contains a zinc and a copper plate which do not touch each other; each zinc plate is connected with the copper of the preceding vessel by a strip of copper, or by a wire. *cs* is a strip of copper soldered to the zinc plate, *sz*, at *s*; *c's'* is a second strip of copper, soldered to a second zinc plate. The copper strip *c's'* is connected with a plate of copper which bends round the zinc plate without touching it. The same condition obtains with respect to every other zinc plate. All the pairs are fastened to a wooden frame, by means of which they may be simultaneously immersed in or raised out of the fluid.

The tension of Voltaic electricity depends upon the number of elements, its quantity upon the size of the plates; we vary our apparatus, therefore, accordingly as we require intensity or quantity. A simple quantity series is represented in *pl.* 20, *fig.* 56. Here *c* is a vessel formed by two cylinders of copper, one within the other. This is filled with acidulated water, and then receives the zinc cylinder, *z*, which is kept from contact with the copper by pieces of cork. A little cup, *b*, is attached to both the zinc and the copper by a wire, and into it mercury is poured for the sake of securing a continuity of circuit when the battery is to be used.

If a battery of very great surface be required, the calorimeter, an invention of the eminent Dr. Hare (*pl.* 20, *fig.* 57), may be used to very great advantage. This, in a form somewhat different from the original, consists of a wooden cylinder about three inches in diameter, and from one to one and a half feet high, on which are rolled two pieces of zinc and copper plate, separated by strips of cloth, forming a pair of plates from fifty to sixty square feet in area.

In all the batteries hitherto described, the action, although energetic at first, rapidly diminishes. This circumstance becomes a great evil when an uninterrupted action of long continuance is required, for which reason Becquerel and others have invented their *constant batteries*. Such a battery is represented in *fig.* 58, *pl.* 20. Here *a* is a cylinder of thin copper, completely closed and coated with sand, *b*. The bottom, *c*, is level, the

top, *d*, conical, with a rim above it perforated with numerous holes. The whole cylinder is inclosed in a bladder, *g*, fastened to the rim, *e*, above the holes; a solution of sulphate of copper is poured upon the conical cover, *d*, which runs through the holes, *f*, and fills the space between the bladder and the cylinder, *a*; in addition, some lumps of sulphate of copper are laid upon the cover, being gradually dissolved by the fluid running over them. The bladder is inclosed in a hollow cylinder of zinc, *h*, with a longitudinal slit, which admits of a variation in its diameter. The whole is immersed in a glass or porcelain vessel, *i*, containing weak sulphuric acid, or a solution of sulphate of zinc, common salt, or some other substance. The strong copper wires, *p* and *n*, soldered to the two cylinders, form the two poles of the battery.

The *constant battery* of Daniel is not essentially different from that of Becquerel. This (*pl.* 20, *figs.* 59, 60) consists of a massive zinc cylinder, surrounded by weak sulphuric acid, placed in a bladder or a hollow cylinder closed beneath, of porous earthenware. The whole is set in a copper vessel filled with a solution of sulphate of copper. *Fig.* 59 exhibits the whole battery of ten elements; *fig.* 60, a section of the upper part of one element. *abcd* is the principal copper vessel; *efgh* the porcelain or earthenware cylinder; *m* the zinc cylinder; *ik* a receiver attached to the upper part of the copper cylinder, perforated at the sides and bottom, and filled with pieces of sulphate of copper; these are constantly in contact with the fluid in the copper cylinder. Each zinc cylinder is connected with the copper cylinder of the succeeding element by a copper wire.

Grove's battery, consisting of zinc and platinum, is remarkably powerful: one element is represented in *pl.* 20, *fig.* 61. The zinc plate is so bent as to form a cell, open above and at the two sides, in which stands a trough of porous porcelain, filled with nitric acid. A slip of platinum, nearly as broad and deep as the porcelain trough, is firmly clamped to the end, *cd*, of the zinc plate, dipping into the porcelain trough of the following pair. Each zinc cylinder thus inclosing a porcelain trough, is set in a glass vessel filled with dilute sulphuric acid, and the several elements, thus arranged, stand together on a wooden frame. Another, and perhaps more convenient arrangement, consists in having a zinc cylinder closed below, and with a binding screw attached. In this, when filled with dilute sulphuric acid, a porous cup containing nitric acid is placed. Over the whole there fits a wooden cover, from the middle of which hangs a slip of platinum foil or platinized silver, dipping into the acid. A second binding screw is in connexion with the upper end of the platinum. These two screws form the poles of the battery.

The *Carbon battery* of Bunsen (*pl.* 20, *fig.* 62), not much less energetic than Grove's, is yet much cheaper, the platinum being replaced by carbon. A cylinder of carbon, open at both ends, is placed in a glass vessel somewhat contracted above, and contains in its cavity a cylinder of porous clay closed below. There is a very slight interval between the two cylinders. The clay cylinder is filled with dilute sulphuric acid; the glass, however, contains concentrated nitric acid, which, after the immersion of the clay cylinder, fills the whole cavity up to the neck. The upper projecting

extremity of the carbon cylinder is turned off conically, and upon it is firmly fixed a zinc ring, *a*, which carries a hollow zinc cylinder, *c*, by means of the bow, *b*. This zinc cylinder dips into the clay cylinder of the following element. *Fig.* 63 exhibits in plan the connexions of the elements of a carbon battery, being a combination of four pairs. Here *p* will be the positive pole, and *n* the negative.

Among the different galvanic arrangements just described, we may distinguish three modifications, whose theory we shall now proceed to explain. The first consists of the pair of metallic plates immersed in a single liquid, and connected externally to the fluid by a metallic conductor, as a copper wire. Let us suppose the fluid to be dilute sulphuric acid. Here the water of the acid is decomposed at the same time with the electricities of the metals, and a current of positive electricity passes from the zinc through the fluid to the copper, thence through the connecting conductor back to the zinc. Negative electricity also passes from the zinc through the connecting conductor to the copper, and back again through the fluid to the zinc. If the connecting wire be severed, the positive current will make its appearance at the portion attached to the copper plate, and the negative at that to the zinc. The extremities of these wires thus attached to the plates are called the *electrodes* or *poles* of the battery. The oxygen of the decomposed water unites with the zinc, forming an oxyde, and this, with the sulphuric acid, forms sulphate of zinc. The hydrogen is carried to the copper plate and there liberated.

The second modification is that in which two fluids are separated by a porous partition, one of them a solution of a metallic salt, as sulphate of copper. This is the case in the constant batteries of Daniel and Becquerel. Here the water of dilute sulphuric acid is decomposed by the current, oxygen being liberated at the zinc plate, and uniting with the zinc, forming an oxyde ; the sulphuric acid then converts this into sulphate of zinc. The hydrogen carried with the positive current through the porous partition assists in decomposing the sulphate of copper, combining with the oxygen of the copper, and liberating sulphuric acid and metallic copper.

The third modification is seen in Grove's and Bunsen's batteries, where nitric acid replaces sulphate of copper ; dilute sulphuric acid here, as in the last modification, forms the second fluid. The action of the oxygen of the decomposed water is the same as in the last case. The hydrogen passing through the porous partition unites with the nitric acid, takes from it an atom of oxygen and forms water, leaving nitrous acid, as shown by the deep red fumes produced.

The *dry pile* still remains to be mentioned, a Voltaic arrangement, in which every two pairs of metallic substances are separated, not by a fluid, but by a dry solid body. Of these the dry pile of Zamboni is best known, and consists of a great number of disks of gold and silver paper, superimposed in pairs, with their metallic faces in contact, and with the same metal always uppermost. Here the paper, being always slightly damp, supplies the place of a fluid conductor. The paper may also be covered with other metallic substances than gold and silver, and is best cut out by a punch. The

pile is preserved in a glass tube, and such pressure exerted upon its top as to maintain the close contact of all the disks, which must be very numerous. The action of this pile, although very slight in comparison with the wet pile, remains constant for months, and even years, on which account it also may be called a constant battery.

One of the most important applications of the dry pile is in the electrometer of Bohnenberger. This is a gold leaf electrometer with, however, but one leaf, towards whose two sides opposite poles of two dry piles are turned. If the least electrical charge be communicated to the gold leaf, which, protected from the air, hangs perfectly quiet when uninterrupted, it will cause the leaf to move to one side or the other. In this manner the character of the electricity imparted can be readily ascertained from the pole, *t*, towards which the leaf inclines. Positive electricity, of course, turns towards the negative pile. In the improvements of Becquerel and Fechner (*pl.* 20, *fig.* 50), a dry pile of 800 to 1000 plates, inclosed in a glass tube, is placed horizontally in a box. The tube is capped with brass at each end, as seen in *fig.* 51. The caps communicate conductively with the poles of the pile, and from them pass the wires, *p* and *f*, terminated by the polar plates, *x* and *y*. The signs + and — are placed on the upper surface of the box from which the poles project, to indicate their electrical character.

3. *The Action of the Galvanic Current.*

As before remarked, a galvanic current is first started when the two poles of a galvanic battery, in working order, are united by a conductor. If the extremities of the two polar wires (*pl.* 20, *fig.* 49) are brought to within a short distance of each other, a spark will be seen to pass between them. By interposing different substances in the current between the poles, very striking and varied electrical effects will be produced. These may be divided into physiological, chemical, and physical. Omitting for the present any mention of the first class, chiefly exhibited in the nervous convulsions of muscular fibre, we pass to the second, the chemical, which consist in the decomposition of water, and of various other compound bodies. Thus water is decomposed by the galvanic current into oxygen and hydrogen, an experiment which the apparatus represented by *fig.* 64, *pl.* 20, is well calculated to exhibit. This consists of a wine-glass, at the bottom of which two platinum wires, *f* and *f'*, are melted in; above these stand two small glass receivers, *o* and *h*, which have been filled with water and inverted in the wine-glass. On bringing the wires, *f* and *f'*, in communication with the poles of a galvanic battery, bubbles of gas will be developed, oxygen rising to the top of the receiver, over the positive pole, and hydrogen over the negative. If the separation of the gases be not necessary, the apparatus represented in *fig.* 65 may be employed. Here the polar extremities are formed by two large plates of platinum, on which the decomposition of the water takes place, the gases ascending to the top

of the receiver, thence to escape mixed together through the bent tube. It is to be observed that oxygen can only be procured in the gaseous state when the positive pole consists of one of the noble metals (gold or platinum best of all): under other circumstances the oxygen unites with the substance of the positive metallic pole, forming an oxyde.

All oxydes and combinations of oxygen, likewise alkalies and salts, are decomposable by the galvanic current in the same manner as water. The decomposition of salts in which the acid appears at the positive pole, and the base at the negative, may be exhibited by the following experiment: Fill a U-formed bent tube (*pl.* 20, *fig.* 66) with a solution of salt, colored violet by litmus, and immerse in one leg the positive, and in the other leg the negative pole of a battery. On establishing a current, the fluid at the positive pole will become red, that at the negative blue, showing that free acid has passed to the former, and alkali to the latter.

One of the most important applications of the chemical action of galvanism is to be found in the recently discovered art of *galvanoplastics* or *electrotype*. In this a constant battery with porous partitions is required, that of Becquerel or Daniel answering very well, with slight modifications. The theory of the electrotype rests upon the decomposition of certain salts, as sulphate of copper, in which the sulphuric acid and oxygen form new combinations, and the copper is precipitated in the metallic state upon the negative element. If this latter have a definite surface, a perfect cast of it will be made by the copper deposited. In this way copies of coins, medals, engraved plates, &c., may readily be taken. *Pl.* 20, *fig.* 67, represents a convenient form of battery for the electrotype. In a large glass cylinder of six or eight inches in diameter, a second and narrower one is suspended, open above, but closed below by a piece of bladder. To sustain the inner cylinder a wire is twisted tightly about it, and from this ring of wire proceed three arms which rest on the edge of the outer cylinder, as seen in the figure. The inner vessel is filled with very dilute sulphuric acid, and the outer with a solution of sulphate of copper; cross-pieces of wood in the inner cylinder support a block of zinc, to which is soldered the copper wire, *c*, thus forming a connexion with the mercury cup on the outside. A second wire, dipping in the same mercury cup, is soldered to the metallic substance of the mould immersed in the sulphate of copper. This substance must be something more electro-negative than zinc, and may consist of Rose's fusible metal (composed of copper, bismuth, and lead), or tin foil, as also of gypsum, wax, stearine, or a mixture of the two latter; these being non-conductors, must be coated with graphite or silver bronze. One of these substances being selected, a cast of the object to be copied is taken in it, and after coating all those parts of the matrix of which no copy is desired, with some resinous solution, it is to be placed in the battery as above mentioned. A due connexion between the poles being established by the mercury in the cup, a slow deposit of copper will take place on the matrix, which may amount to a considerable thickness in the course of some hours or days.

It is not copper alone that may be deposited from its solutions in a

chemically pure condition, but also gold, silver, platinum, and other metals. More recently the various operations of gilding, silvering, plating, &c., have been carried to great perfection and into new applications by the electrotype. For full details on this interesting subject we would refer our readers to the various works of Smee, C. V. Walker, Becquerel, and others.

As electricity exercises a chemical action, so it may be proved that any chemical combination or decomposition developes electricity. The combustion of carbon may serve as an illustration, where the carbonic acid produced is positively electric, while the carbon itself is negative. To prove this, take a suitable cylindrical piece of charcoal, and stand it upon a long brass plate (*pl.* 22, *fig.* 13), attached to one plate of a condenser. Set the coal on fire and keep up a vigorous combustion by means of a pair of bellows; on connecting the lower plate of the condenser with the earth the whole apparatus will soon be charged with negative electricity. To collect the positive electricity, place the charcoal on a plate in communication with the earth, and hold it under the above-mentioned brass plate.

The physical effects of the galvanic current consist partly in the development of light and heat, partly in the exhibition of magnetic phenomena. Oersted first suggested the intimate connexion between magnetism and electricity, by his discovery that a freely suspended magnetic needle is deflected whenever it is brought near the terminating wire of a battery in full action. Electricity at rest or in a state of great tension does not produce this phenomenon. The experiment is best performed in the following manner: Form a rectangle of eight or ten inches in diameter out of a strong copper wire (*pl.* 20, *fig.* 68), bring its plane into that of the magnetic meridian, and connect the extremities of the wire, *ab* and *fg*, with the poles of a battery of large surface. If *ab* be connected with the positive and *fg* with the negative pole, the positive current will circulate in the direction of the arrows. Now, if a magnetic needle be held *above* the branch *cd*, the north pole will be deflected towards the east, and towards the west when held *below cd*. The action will be precisely the reverse at the branch *ef*. To assist the memory in recollecting the various directions of deflection under different circumstances, Ampère has suggested the following method: A little human figure is imagined as attached to any one branch of the wire, with the positive current always passing in at the feet and out at the head. The figure being supposed always to have its face turned towards the needle, the deflection of the north pole will ever take place towards its left hand.

The *multiplier* or *galvanometer* of Schweigger depends for its principle upon this deflecting power of the galvanic current in the various forms of this instrument, this power being increased by multiplying the windings of the wire. All the portions of the galvanic current which pass in the direction of the arrows of the elongated rectangle (*pl.* 20, *fig.* 69) act in the same direction upon the inclosed magnetic needle; if then a wire pass round the needle in, say 100 turns, all traversed by the same current,

they must exert a deflecting influence 100 times greater than that of a single turn. For this purpose a copper wire, fifty or sixty feet long, and covered with silk, is wound around a rectangular frame of wood or metal, so as to leave the two extremities free; within this frame a magnetic needle is to be suspended from a fibre of silk. The entire apparatus, covered by a glass receiver, is termed a *multiplier*, and serves to render sensible the feeblest galvanic current, or the least trace of galvanism. Nobili, however, rendered the multiplier much more sensitive by employing a system of two needles (*fig.* 70) instead of one: these are combined on a straw or thin wire with their similar poles in opposite directions. The terrestrial polarity of the needles being thus destroyed, the *astatic needle* is free to obey the deflecting force of the very feeblest trace of galvanism. One needle hangs within and the other without the turns of the wire, both being thus deflected in the same direction. The upper needle traverses a circle graduated to 360°, pointing to 0° when no current passes through the coil; the more powerful the current the greater the deflection from this position. *Pl.* 22, *fig.* 48, represents the whole of an *astatic multiplier*, and *fig.* 49 the frame with its windings seen from above; *n* and *p* are the extremities of the windings to be connected with the poles of the battery.

The tangent and the sine compass likewise depend upon the deflecting force exercised by the galvanic current on the magnetic needle. They can only be used with the more powerful currents, but nevertheless have this advantage over the multipliers, that in them the angle of deviation is in very simple proportion to the strength of the current. Thus in the tangent compass the strength of the current is proportional to the tangent, and in the sine compass to the sine of the angle of deviation. *Pl.* 20, *fig.* 71, represents a *tangent compass* according to the construction of Weber. Here the current is carried around the magnetic needle through a broad circular copper strip whose plane must lie in that of the meridian. The needle, which need not be astatic, is in the centre of the copper hoop, and is very small in proportion to it. The current is carried to the hoop through a copper rod, and is brought back through a hollow copper cylinder, inclosing the rod without being in conductive contact with it (see *figs.* 72–74): *a* and *b* (*fig.* 71) are the mercury cups in which the electrodes are dipped. The *sine compass* is shown in *fig.* 75. In this instrument the needle is placed in the centre of a horizontal graduated circle turning about a vertical axis, and about which the multiplying wire (in one or more turns) is wound. The instrument is set up so that the plane of the multiplier lies in the magnetic meridian.

Difference between compound and simple batteries.—The actual quantity or amount of current electricity is no greater in a compound battery than in one of its simple components, provided that the closing of the circuit is produced throughout by good conductors; it depends, not upon the number, but upon the size of the plates. On the other hand, the tension or intensity of the electricity increases with the number of pairs; therefore, in those cases where a bad conductor is interpolated in the circuit, as the human

body, it becomes necessary to employ series of many pairs. By connecting the positive poles of several elements, and likewise the negative, we obtain the equivalent of a single pair or element of greater surface. *Pl.* 22, *fig.* 54, illustrates this combination. Here A is an element closed by the wire *abc*, B is a second element; the positive poles of both are united at *a*, and the negative at *c*.

D. Electro-Magnetism.

a. Magnetic Action of the Galvanic Current.

We shall now proceed to treat more in detail of the magnetic actions of the galvanic current. The most important of these consists in its being able to render iron, steel, and even other metals, magnetic. Wind a copper wire spirally round a glass tube, and within this lay a fine sewing needle. If, now, a galvanic current be passed through the wire for a short time, the needle will become permanently magnetic. In right-handed spirals or coils (*pl.* 20, *fig.* 76), where the turns are as in the common screw, the north end of the needle will be where the positive current enters; in left-handed (*fig.* 77), where it emerges. If, on the same tube, the wire be wound alternately right and left (*fig.* 78), several successive poles will be formed in the needle. In this manner magnets of extraordinary power may be obtained from soft iron. For this purpose, a strong piece of iron bent into the horse-shoe form is to be wrapped round with insulated copper wire (*pl.* 20. *fig.* 79). The wire must be wound in the same direction on both legs. If the winding be right-handed, then the north pole will be where the positive current enters, as at *a*, the south pole being at *b*. A single pair of plates of large surface is generally used with this *electro-magnet*. If several small elements are employed, a greater number of windings will be required. *Figs.* 80 and 81, *pl.* 20, represent a powerful electro-magnet, capable of sustaining over 2000 lbs. It consists of two cylindrical pieces of iron, each about three and a half inches thick, and from two to two and a half feet long, bent into the horse-shoe form; both arms are wrapped with a copper wire, insulated by being covered with silk, about three thousand feet long and one fortieth of an inch thick. The galvanic series producing the current consists of thirty-four pairs of plates. When the current begins to circulate, the lower movable electro-magnet, *a'b'*, is attracted by the upper, and both are attached so firmly that the immense weight of one ton may be laid upon the board, *cc*, without separating the electro-magnets. The honor of first applying the principle of the electro-magnet to the production of very large magnets, is due to Prof. Joseph Henry.

On account of the powerful magnetic action of the galvanic current, the idea early presented itself of using electro-magnetism as a motive power. Instruments for this purpose are called electro-magnetic machines. *Pl.* 22, *figs.* 36–38, represent one form of the electro-magnetic machine as constructed by Stöhrer of Leipzig, in 1841: the action of this depends upon

the alternate attraction and repulsion of bar electro-magnets. The machine consists of a wooden frame; the posts, *b*, *b*, *b*, *b*, carry two rings, *cc* and *hh*, to whose inner circumference twelve electro-magnets, *d*, *d*, *d*, are fastened at equal distances apart. Twelve other electro-magnets, *g*, *g*, *g*, are attached to the wheel of the axle, *e*. All the electro-magnets have projecting pieces of iron at their extremities, so that the inner moving system passes very close to the outer fixed one. An arrangement, *i*, is fastened to the axle above the electro-magnets; it is shown from above in *fig.* 38. This *commutator* is intended to reverse the direction of the current traversing the wires of the electro-magnets twelve times in each revolution; by this means the polarity of the electro-magnets is reversed the same number of times. The current from the battery enters the machine through one of the conducting wires, *s*, into the turns of the first fixed electro-magnet, and these being connected with each other, the current passes through all the coils. From the last bar, a communication at *k* leads into an arrangement shown in *fig.* 37, which carries the current through the commutator to the movable bars. After these coils have been traversed, the fluid passes through the second wire of the same arrangement, *t* (*fig.* 37), and through the second conducting wire, *s*, back again to the battery.

On the introduction of the electric current all the bars become magnetic, the fixed system attracting the movable until the two are opposite to each other. At this moment the poles of the movable magnets are reversed, and the previous attraction becomes a repulsion. The momentum of the rotating mass has carried it, however, a little beyond the point where the two systems are diametrically opposite; this repulsion then acts to impel the movable system in the same direction as before. At the same time the magnet thus repelled by one fixed magnet, is attracted by the next fixed one, since the windings of the coils are so adjusted as to cause the north and south poles of the latter system to alternate at their upper extremities. This alternate attraction and repulsion existing between each fixed and movable magnet, soon imparts to the axle a rapid and uniform rotation. This is communicated to the horizontal axle, *p*, by means of the bevelled wheels, *n*, *m*, unless these should be thrown out of gear by the lever arrangement at *o*. The anterior extremity of the horizontal axle carries a pulley, *p*, with rope and hook, *q*, for raising weights. At the lower end of the vertical axle there is a horizontal wheel, *rr*, with an endless rope passing round it, by which means a rotary motion may be communicated to any object, a turning lathe for instance. Indeed, the machine was actually used for this purpose by its inventor.

The *commutator* (*pl.* 22, *fig.* 38) consists of a plate of wood with metal strips let into its surface. These strips are all connected internally in such a manner that all those lying in the same circle are in metallic communication with each other. Of the four metal rings, the first and second, and the third and fourth, are likewise in metallic communication. The two extremities of the wire of the movable magnet pass each to one of these two combinations.

The arrangement (*fig.* 37) is set into the wooden frame (*fig.* 36) at *k*,

in such a manner that the four movable metal rods, *a'*, *a'*, *a'*, *a'* (*fig.* 37), corresponding to the four rows of inlaid metal strips (*fig.* 38), fall down by their own weight, resting on these circles of strips, and thus conduct the current from the fixed to the movable coils. Of the four rods, the two inner and the two outer ones communicate with each other alone, while the combination of the rows of strips in *fig.* 38 is just the reverse. When the axle with the commutator is set in motion it will be seen that two contiguous rods, *a'*, *a'*, alternately restore and interrupt the conduction to the commutator, and by the varying combinations in the two systems produce an alternation in the direction of the current in the movable coils.

The battery employed with this machine is a Daniel's battery improved by Stöhrer. Copper cylinders, *v*, *v*, *v*, *v* (*fig.* 36), have expansions above in which crystals of sulphate of copper are laid. Inside of the cylinder hangs a hempen bag with a wooden bottom ; on this is placed a cylinder of cast or sheet zinc. The bag is filled with very dilute sulphuric acid, and the copper cylinder outside of the bag with sulphate of copper. The action of the acid on the zinc results in the development of a current and the decomposition of part of the water combined with the acid. The hydrogen carried along with the positive current passes through the bag, and uniting with the oxyde of the sulphate of copper, liberates sulphuric acid and metallic copper. In combining the four batteries represented in the plate the usual method is employed, the zinc of the first and the copper of the last being left free for connexion with the wires communicating with the machine. This, when in full operation, may have a velocity amounting to 230 or 240 rotations in a minute.

The apparatus represented in *pl.* 22, *fig.* 39, an improvement of Ritchie's apparatus, is of similar construction. Here AB is a large horse-shoe bar of soft iron, fastened to a wooden frame and wound with copper wire, whose extremities are conducted to the brass posts, *a* and *b*, having binding screws above. If the electrodes of a strong galvanic battery be screwed to these posts, the iron AB will become converted into a magnet. Within this iron is a second, CD, of similar shape but of smaller size. This rotates on a vertical axis, and is also wound with copper wire, whose two extremities dip into a circular channel filled with mercury. The channel is separated into two semicircles by bridges of wood or cork, each of which is connected conductively with one of the posts, *c* and *d*. The channel is so filled with mercury that this projects slightly above the bridges without running over, owing to its capillarity. The wires dip into the mercury enough to insure conducting communication and yet not enough to touch the bridges. If the positive electrode of a battery be screwed in *c*, and the negative in *d*, then in the position represented in the figure, the positive current will pass from *c* into the left division of the channel, then round through the coil of copper wire from D to C, thence through the right division of the channel to *d*. In this instance the pole C is attracted by A, and D by B, thereby producing a partial rotation of the electro-magnet, CD. When C has reached A, and D has reached B, the extremities of the rotating wires cross the bridges

and the current, for an instant interrupted, immediately sets in again in the opposite direction, thus reversing the magnetism of the poles C and D. Respectively of like character with A and B, they are now repelled, and thus driven round in the same direction until a recond reversal of their poles results in a second attraction. A spur wheel is attached to the upper extremity of the axis of the inner electro-magnet, which sets in motion the other apparatus shown in the figure, for the purpose of raising a weight. We may remark, in conclusion, that electro-magnetism has not answered the expectations formed of it as a motive power, the cost being as yet too great. Experiments are now in progress, however, which may result in showing its applicability to many purposes.

The *electric*, or more properly *electro-magnetic telegraph*, is perhaps the most important result of the rapid communication of galvanism through conducting wires, and its electro-magnetic properties. It was first proposed by Ampère about 1823 to be operated by means of galvanometers. In 1825 Professor Barlow of Woolwich made a series of experiments, and found that the power diminished so rapidly with the distance that he pronounced the scheme impracticable. The next step in the discovery was made by Sturgeon about the same time. He bent a thick iron wire in the form of a horse-shoe, and rendered it magnetic by a galvanic current. Nothing further was done in reference to this subject until Professor Henry's experiments in 1830, published in 1831 in Silliman's Journal. He repeated the experiments of Barlow with the galvanometer and single battery, and found the same result. He next substituted for the galvanometer an electro-magnetic magnet, and again obtained similar effects. He afterwards changed the form of the battery and used one of intensity, and then found that the electro-magnet could be made to act at a distance, and announced the applicability of these results to the formation of the electro-magnetic telegraph. He also gave an account of two kinds of electro-magnetic magnets, both of which are now employed in the magnetic telegraph, one to be used with the single battery, formed of a number of short strands of copper wire, and the other in the long circuit with a compound battery, and formed with one long wire coiled around the magnet. The first, or a modification of it, is now employed as the relay magnet, and the second is the magnet of the long circuit.

Referring our readers to professed works on the subject for additional facts in the history of the electro-telegraph, we proceed directly to an explanation of some of the principal forms that have been suggested and employed in various parts of the world. Of these, the first to be mentioned is *Wheatstone's telegraph* (*pl.* 22, *fig.* 40). Two horse-shoe electro-magnets are fastened to a board, and wound with copper wire insulated by a silk wrapping. One extremity of the wire wound around the left horse-shoe passes under the board to the brass post *a*, the other goes to the post *b*. Other wires are screwed to these posts, passing to a point at some distance from the horse-shoes, where there is a galvanic battery. On bringing these conducting wires last mentioned into communication with the opposite poles of the battery, the left horse-shoe will become magnetic, this magnetism

immediately vanishing on breaking the connexion of one wire. A third wire passes from the place where the battery is situated to the third post, *c*, placed on the same board with *a* and *b*; the extremities of the coil wound around the right-hand horse-shoe pass to *b* and *c*, so that this can be rendered alternately magnetic or not. In front of the poles of the right horse-shoe is an iron plate, moving backwards and forwards on two pins at its lower end; to this is fastened a vertical beam, carrying above the cross-piece *d*. When the horse-shoe becomes magnetic it attracts the iron; on losing this magnetism the attraction ceases, and a weak spring pressing against the beam throws it off again. In this manner a backward and forward motion of the cross-piece, *d*, is effected. At each end of the latter is a small ball which strikes a little bell at every backward and forward motion, consequently a person standing at the battery can make signals through the bell. The left horse-shoe has a similar plate, with a beam carrying the cross-piece *rs*. At each end of the cross-piece are pieces which catch alternately in the teeth of a twelve-toothed wheel in such a manner that at each backward and forward motion of the iron plate the wheel is moved forward one tooth. The axis of the toothed wheel passes through the centre of a disk of sheet iron, to which also the bell is fastened. Upon the borders of this disk (in our figure on the face opposite to the spectator) twenty-four signals are painted at equal distances, viz. twenty-three letters of the alphabet (exclusive of X and Y), and a point. An index on the same side of the disk, carried by the axis of the toothed wheel, is by the rotation of the latter moved forward one letter at each opening or closing of the circuit. When the index is set to the point (.), closing the circuit carries it to A, opening it again to B, &c., consequently an operator at the battery can make the index point to any letter on the disk, making a signal with the bell when the letter intended is reached. To avoid any error here, an apparatus is applied close to the battery, to regulate the opening and closing of the circuit: *p* and *n* are the two poles of the battery; from *p* an insulated copper wire passes to the brass post, *b*, of the recording apparatus; from the negative pole, *n*, there passes a shorter wire to the post, *l*, of the regulating apparatus. On this apparatus, besides *l*, there are two other posts, *m* and *q*, into which the wires coming from *a* and *c* are screwed. Communication is established between *l* and the brass spring *tu*, not visible in the figure. On pressing this down it touches a button projecting from *q*, and the current passes from *p* through *b*, *c*, *q*, *l*, to *n*, the current thus being closed. Let the spring *tu* fly back again and the current is broken, the circuit being opened.

A second brass spring proceeding from the post *l*, when not depressed, touches a button on *m*, and thereby closes the circuit, so that the current from the positive pole passes through *b*, *a*, *m*, *l*, to the negative pole, *n*, of the battery. Depressing the spring of course interrupts the current. Over the middle of the last mentioned spring there is a disk turning about a horizontal axis, in whose circumference are inserted twenty-four rods or spokes, alternately long and short. Of these, one of the larger ones is

indicated by a point, the others are indicated by letters of the alphabet in their proper succession, as in the recording apparatus.

The figure represents the apparatus at the time when a message is about to be transmitted. The operator, by depressing the spring *tu*, gives by means of the bell a signal of warning to the operator at the other station. He then turns the wheel so that the short spoke marked A is vertically underneath. The spring *lm* immediately flies up, and the circuit is closed, thus causing the index at the other station to point to A. Moving the wheel again until the long spoke marked B is underneath, the circuit will be broken, and the index of the recording apparatus will point to B. In this manner the operator continues until he comes to the letter to be signalized, when the other spring is touched and the bell rung to indicate that the proper letter has been reached. The index of the one apparatus and the wheel of the other are then to be brought back again to the point (•), to begin afresh with the next letter.

Figs. 41 and 42, *pl.* 22, represent the working part of *Steinheil's electric telegraph*, laid down by him in 1837 between his residence in Munich, the physical cabinet of the Academy building in that city, and the Royal Observatory in Bogenhausen, near Munich, a distance of 37,000 feet. The conductor consisted of three portions : 30,500 feet of copper wire between the Academy and the observatory, carried through the air and stretched over the steeples of the city ; 6000 feet of iron wire between the Academy building to Steinheil's dwelling-house and back again, likewise carried through the air ; and 1000 feet of copper wire in the Academy building itself, extending to the machine-shop of the physical cabinet, carried along the joints of the floor, and partly embedded in masonry. The exciting apparatus, instead of being a galvanic battery as in the preceding telegraphs, is a Clarke's magneto-electric machine. This consisted of a compound horse-shoe magnet of seventeen plates of hardened steel, weighing, when armed, sixty pounds, and possessing a power of 3000lbs. The reversal of the current is effected without a commutator by the turning of the inductive coils in the opposite direction. The momentary connexion of each conducting wire with the magneto-electric battery moves a horizontal balancer, ending in two metal balls, which need only be moved to the right or left to give the signs. To prevent the mercury from being spilled by the hooks in the rapid rotation of the multiplier, a cylindrical glass ring (*pl.* 22, *fig.* 41) is placed over the mercury vessel. Small magnetic bars, sixty millimetres long, ten high, and eight broad, are used for making the signs ; they are fixed by twos, one in the prolongation of the other, in the frame of a multiplier interpolated in the circuit. In either direction of the current only one of the magnets can be moved. At the inner and contiguous extremities of these bars are small vessels running out into horizontal beaks with capillary apertures. When these vessels are filled with a fluid oil black, the extremities will leave the impression of a point on a strip of paper, moved along by clock-work, with which they are brought into contact. This paper is prepared for use by

taking a wide cylinder of paper consisting of a very wide strip wound round an axis, and cutting this on a turning lathe into short cylinders of equal diameter, and of a height equal to the width of the strip. One of these cylinder strips is to be placed in the proper part of the machine, the extremity unwound and then wrapped round a second cylinder, the unwound portion passing by the ink points. The cylinders of paper are turned by clock-work. *Fig.* 41 exhibits the entire machinery in longitudinal section; *fig.* 42 is the apparatus from above. Thirty different symbols are obtained by the varying positions of points; of these twenty-two are letters and ten numeral signs, the letters *c, q, u, x, y,* being omitted, while *ch* and *sch* are added. The figures 0 and 9 are expressed by the similarly shaped letters *o* and *g*. One high point indicates *i*, one low *e;* two high *n*, two low *r;* three high *m*, three low *o;* four high *h*, four low *ch: d* is indicated by •.; *t* by .•; *a* by .•.; *v* by •.•; *f* by .••; *g* by ••.; *k* by ..•; *l* by •..; *b* by .•••; *sch* by .•.•; *p* by •...; *s* by ..••; *w* by •.•.; *z* by ••.. Of the numerals 1 is indicated by .••••; 2 by •.•••; 3 by ••.•••; 4 by •••.; 5 by •....; 6 by .•...; 7 by ..•..; 8 by ...• Instead of points on a strip of paper, the signals may be made by the higher and lower tones, differing by about a sixth, of two metal or glass bells. It is evident that the same magnetic bars cannot write and strike simultaneously, on account of possessing too little power. In the neighborhood of the signal magnets are small magnets separated from them, and so placed as to bring back the former to their original position after striking; this renders it possible to make the signs with great rapidity (five times in a second). Small bells are used in this telegraph as in the last, to call the attention of the observer at the station whither the message is to be sent. In conclusion, *pl.* 22, *fig.* 42, represents the upper view, and *fig.* 41 the longitudinal section of a table standing on the floor of the room, and containing all the apparatus. The circuit wires, the ends of the multiplier, and two conductors from the mercury vessel of the inductor, meet, as shown in *fig.* 42, in the centre of the table, where they pass into eight holes filled with mercury, made in a wooden cylinder. Upon the different connexions of these mercury holes the direction of the current depends. As the balance moves from right to left, or the reverse, one or the other signal marker is deflected, thus producing a higher or lower point (or tone). As long as the intervals of time between the single signs are equal these all belong to the same group. Different groups are separated by a longer pause, producing a longer interspace.

The simplest of all telegraphs, and the one best adapted to the practical purpose of communicating intelligence from one part of a country to another, is unquestionably the one used in the United States, and known as *Morse's telegraph.* A single wire only is here employed, which passes from the transmitting station to the receiving, and is there wound round an electro-magnet in the form of a horse-shoe. A plate of soft iron attached to one end of a lever is situated immediately above the extremities of the horse-shoe; the other extremity of the lever carries a point. The strips of

paper on which the signs are to be made pass under a roller immediately above this point, being unwound from a coil, *l*, and worked by clock-work, as in *Steinheil's* telegraph. When the horse-shoe becomes magnetic, it attracts the plate above it, by which means that extremity of the lever is depressed. The other end being elevated causes the steel point to strike into the strip of paper. As this strip is constantly moving under the above-mentioned roller, a sudden closing and opening of the circuit will produce a point on the paper; if the circuit be kept closed for an appreciable period, the point being pressed all the time against the paper, a line will be made. Thus by the combination of dots and lines, a series of symbols answering to the alphabet will be produced.

The most important laws of the magnetic action of the galvanic current, as worked out after numerous experiments by Jacobi and Lenz, are the following: 1. The amount of magnetism is proportional, other things being equal, to the strength of the galvanic current employed; 2. The thickness of the wire of the coil exerts no influence on the strength of the current; 3. Neither does the diameter of the coil, if the iron projects far enough from it. It is thus all the same whether some of the windings are carried immediately about the middle of the iron, as in *pl.* 22, *fig.* 66, or at some distance, as in *fig.* 67. 4. The combined action of all the windings is equal to the sum of the actions of the single turns; 5. The magnetism of iron bars or rods of equal length, other circumstances being equal, is proportional to their diameters.

As the galvanic current exercises magnetic influence, so on the other hand the magnet acts on the galvanic current. The influence of terrestrial magnetism is especially interesting in this respect. To detect this it is necessary to impart to the current a high degree of mobility, for which the apparatus of Ampère, represented in *pl.* 20, *fig.* 83, is especially calculated. Here *t* and *v* are two brass pillars fixed in a board, and carrying horizontal arms above, which appear to be in contact, but in reality are separated by some non-conducting substance; at the extremities of these arms are the two small cups, *x* and *y*, standing one above the other. When the feet of the pillars are brought into communication with the poles of a working battery, one cup becomes positively, the other negatively electrified. The contrivance represented in *fig.* 84 is intended for more readily breaking the connexion with the feet of the pillars and restoring it in the opposite direction. Here *r*, *r'*, are two grooves in a board, several lines thick; *v* and *v'*, *t* and *t'*, four holes which are connected in pairs by copper strips, namely, *v* with *v'* by *ll*, *t* with *t* by *mm*. Where the strips cross each other they are separated by non-conductors. All the grooves and holes are varnished and filled with mercury. If *r* be connected with *v*, *r'* with *t*, and the positive electrode dipped in the groove *r*, and the negative in *r'*, the electricity is distributed in the wire *v*, from *t* to *t'*, and the metal strips, *b'* and *b*, connected with *v'* and *t*, become, the former positive, the latter negative. On the other hand, if *r* be connected with *t'*, and *r'* with *v'*, then *b* will be positive and *b'* negative. If both strips are connected by a wire, as in the

figure, the positive current passes from *b* to *b'*, or the reverse, as *b* or *b'* is positive or negative. To restore one of the two above-mentioned connexions at pleasure, the wooden swing-beam represented in *pl.* 20, *fig.* 85, may be employed; this turns on an axis, *aa'*, and carries four bent conductors, *d*, *d'*, *e*, *e'*. The two former are elevated in the figure, the two latter connect *r* with *v*, and *r'* with *t*; when *e* and *e'* are elevated, *r* is connected with *t* by *d*, and *r'* with *v'* by *d'*. This apparatus, termed *gyrotrope*, is attached at the feet of the pillars, *v* and *t*, of *fig.* 83, these being united by the strips *b* and *b'*. Taking now a copper wire bent into a circular form, and immersing its steel-pointed extremities in the mercury cups, *x* and *y*, of *fig.* 83, the wire will turn and arrange itself with its plane forming a right angle with the magnetic meridian, the positive current passing in the lower half of the circle from east to west. Reverse the current by means of the gyrotrope, and the circle will make a semi-revolution. The result will be precisely the same with a wire bent at right angles. A combination of several circular wires, parallel to each other and traversed by the current in the same direction, places itself, like a single circular current, at right angles to the magnetic meridian. Therefore the spiral wire (*pl.* 22, *fig.* 8), when suspended to an Ampère stand, and traversed by a current, must so place itself that the axis of the spiral shall fall in the direction of the declination compass, so that the latter may be imitated by such a spiral.

The apparatus of De la Rive (*pl.* 20, *fig.* 88) shows that even feeble currents are thus affected by magnetism. Two plates, one of zinc, the other of copper, are fastened to a piece of cork, and united above the cork by a copper wire wound either circularly or as in the figure. On placing the cork on slightly acidulated water, a galvanic current is immediately produced, strong enough to be directed by terrestrial magnetism, or to be attracted and repelled by a magnet. To examine the influence of a magnet on a galvanic current entirely free from the complication of terrestrial magnetism, an apparatus must be employed in which the influence of terrestrial magnetism neutralizes itself, as is the case in the double rectangle shown in *pl.* 20, *fig.* 86. Here a wire, symmetrical on both sides of the axis of rotation, is traversed by the galvanic current in one direction. On suspending such a rectangle from the Ampère stand, it remains in equilibrium in all directions, but is attracted or repelled by the poles of a magnet.

It is necessary to distinguish between the action of terrestrial magnetism on vertical and on horizontal currents. For vertical currents we may make use of the apparatus represented in *pl.* 22, *fig.* 1, which consists of two cylindrical copper vessels filled with acidulated water, the lower cylinder having rather the greater diameter. Both have a cylindrical aperture in the centre, through which passes a rod, *t*, whose upper extremity forms a mercury cup. The cross-piece, *hh'*, of some non-conducting material, has a pivot point in its middle; on this point it rests in the bottom of the mercury cup, and is capable of free rotation. The lower extremities of the wires *vv'* dip into the fluid of the lower vessel; above, after some windings, they are fastened on the cross-piece, *hh'*, and then dip into the

water of the upper vessel. The lower vessel is connected with one pole of the battery, the rod *t* with the other. Now, if the positive current enters the lower vessel it rises through the wires *v* and *v'*, descending again through the rod *t;* the system has, however, no directive power, since equal and opposite forces act on each wire. By taking one extremity of the inner wire from one or the other vessel, the current can ascend only through *one* wire, and the system, under the influence of terrestrial magnetism, will place itself at right angles to the plane of the magnetic meridian.

Two galvanic currents exert a magnetic influence on each other, attraction existing between two parallel currents when their direction is the same, and repulsion when this is opposite. The apparatus figured in *fig.* 4, *pl.* 22, is intended to illustrate these facts. Here *abcdef* is a copper rectangle, suspended in the mercury cups *x* and *y*. The galvanic current ascends through the post *t*, traverses the rectangle in the direction of the arrows, and descends along the post *v*. It is evident that the current in the post *t* is the same in direction with that in the wire *de*, and that in *v* the same with that in *bc*. On bringing the rectangle out of this position, it will again return to it, owing to the attraction between *t* and *de*, and between *v* and *bc*.

If a wire be doubled, as in *fig.* 70, *pl.* 22 (left hand), we have two currents which move in opposite directions to each other, and therefore produce no effect. That the action of a curved current is equal to that of a rectilineal of equal intensity, and whose length is equal to the direct distance between the extremities of the curved one, may be shown with the help of the wire represented on the right hand of *fig.* 70. This must be wrapped with silk to prevent any passage of galvanism from one wire to the other. On allowing a current to pass through the straight wire, which descends again through the bent one, this current will exert no influence on the rectangle (*pl.* 22, *fig.* 4), consequently the actions of the two wires must mutually balance each other.

Two currents not parallel (crossed) exhibit a tendency to become parallel, and to move in the same direction; consequently, those parts of the current moving towards the crossing point attract, while one going and one returning repel each other. This may be shown by means of an apparatus exhibited sectionally by *fig.* 5, *pl.* 22, and in plan by *fig.* 6. Two semicircular channels made in a wooden disk are filled with mercury and separated by insulating walls, *a* and *b*. A pivot point projects from the centre of the disk, upon which rests a copper needle, *cd*, with iron points; a little below it lies another, *ef*, movable by hand, whose extremities are also of iron, and dip into the mercury. The current entering at *x* goes into one channel, then through both needles into the other, escaping at *y*. Giving the needles the position of *pl.* 22, *fig.* 6, the parts *cr* and *er* repel each other, as also *dr* and *fr*. Bring them into such a position that the angle *erd* is less than 90°, and the above-mentioned parts attract each other.

Ampère has propounded a very ingenious theory in explanation of these phenomena. According to this savant, every particle of a magnet is encircled

by a circular electric current returning into itself. The transverse section of a magnetic bar will then be something as in *pl.* 22, *fig.* 43, although a magnetic bar may also be considered as a system of parallel closed currents, as shown in *fig.* 44. Let us imagine a wire helix extending from *m* (*pl.* 20, *figs.* 89, 90) in both directions, and traversed by a current in the direction of the arrows; let us further suppose this helix to be severed at *m*, and both parts separated, then there will be produced a south pole at *a* and a north pole at *b*, both attracting each other. Circulating currents may be imagined even in the interior of the earth, which are parallel to the magnetic equator; instead of these, however, we may suppose a single current, the mean terrestrial current, which passes from east to west, lying, for each place, in a plane perpendicular to the dipping needle. The latter may be shown by the apparatus, *pl.* 22, *fig.* 7. If this be placed with the horizontal axis of rotation perpendicular to the magnetic meridian, then the plane in which the rectangular current places itself in equilibrium, must be parallel to the plane of the terrestrial current; the experiment, however, shows that this is exactly perpendicular to the direction of the dipping needle.

Ampère's theory also explains the rotation of a movable current about a magnet, as is shown by the apparatus figured in *pl.* 22, *fig.* 45. A horizontal bar, *d*, may be moved up and down the vertical rod *l*, and fixed at any position. The bar *d* carries a brass ring, on which is set a wooden channel for holding mercury. In this is stuck a cork disk, through whose centre passes a vertical magnetic bar, *mm*, at whose upper extremity is screwed a socket with a steel mercury cup, *p*. A fine pivot rotating in the cup carries a copper stirrup, *b*, which is bent down at both ends, and whose platinum-pointed extremities dip into the mercury channel; in its centre is a second mercury cup. On dipping one electrode of a battery into this cup, and the other into the mercury channel, the current will traverse both arms of the copper stirrup, which will begin to rotate about the magnet.

Another apparatus, invented by Faraday, which begets its own current, thus dispensing with a battery, is shown in *pl.* 22, *fig.* 3. Here *zz* is a vessel of zinc containing acidulated water, and perforated in the centre; above the centre of the aperture a cross-piece of zinc is laid, and to it is fastened a copper rod, *sc*, ending above in a mercury cup. From this cup is suspended the apparatus shown in *fig.* 2, the lower part being a ring of copper. The positive current here passes from the zinc through the acidulated water into the copper ring, then ascends through the wires, and descends again through the copper rod *cs* into the zinc. A rapid rotation will immediately ensue whenever a magnet is brought under the vessel. *Fig.* 3 represents the arrangement of *fig.* 2 as set in the mercury cup *cs*.

For the same reason a movable magnet will rotate about a fixed immovable current. To prove this it is only necessary to make a slight alteration in the apparatus shown in *pl.* 22, *fig.* 45. For this purpose, remove the cork disk with the magnetic bar *m*, and the copper stirrup *b*, and fix the horizontal beam, *d*, in such a position that the upper extremity of the copper rod, *s*, shall be exactly opposite the centre of the wooden channel (*fig.* 46). At this upper extremity there is a mercury cup, into which, suspended by a

thread, there dips a metallic bar, without touching the bottom. A horizontal cross-beam is fastened to this metallic bar, ending in two balls, into which are inserted two bar magnets with their similar poles in the same direction. Another metallic bar is fixed at right angles to the middle of the horizontal bar, ending in a bent point which dips into the mercury channel. Now, if one pole of the battery be dipped into the mercury cup, *q*, and the other into the channel, the current will either pass from *q* through *s*, and from the upper end of the rod *s* into the channel, or it will move in the opposite direction. As soon as the current starts, the entire system, with the two bar magnets, begins to rotate about the axis formed by the thread. The direction of rotation depends partly upon which pole of the magnets is superior, and partly upon the direction of the current.

The stand figured in *pl.* 22, *figs.* 45, 46, by the modification shown in *fig.* 47 may be also used to cause a magnet to rotate about its own axis. The wooden channel has here the same position as in *fig.* 45, the cork disk and magnet *m*, and stirrup *b*, only being moved. In their stead a bar magnet is suspended from a silk thread passing through the centre of the channel, a part of its length lying above, and a part below the plane of the channel. A socket screwed to the upper end of this magnet carries a mercury cup, *t*, in whose centre the thread is fastened by which the magnet is suspended. From a second socket which is screwed on the bar magnet at the level of the channel, there passes a metallic bar with a bent platinum point which dips into the mercury of the channel. As soon as one electrode of the battery is dipped into the mercury cup, *t*, and the other into the channel, the magnet commences to rotate about its axis. This rotation of a magnet about its own axis is explained by Ampère in the following manner: let *abcd* (*fig.* 9, *pl.* 22) be the section of the magnet with the plane of the mercury, and let *ab* be one of the currents passing from the magnet through the mercury to the negative pole, then *ab* will be attracted by *af*, and *ad* repelled, so that the magnet must turn in a direction opposite to that of the currents of the magnet. In the figure, the curved arrows within the magnet indicate the direction of the current; those without, that of rotation.

In *pl.* 22, *fig.* 10, let P be the centre of the vessel to whose circumference the current passes through the mercury. Let the shaded circle represent the section of the magnet, and the arrows surrounding it the direction of the currents forming the magnet. Considering the direction of the currents, PA, PA′, tangent to the magnet, the former produces a repulsion in the direction from *m* to *c*, the latter an attraction in the direction *cm*′. Both forces unite in a single one, acting in the direction from *c* to T′. Two other currents, as PB and PB′, one each side of the magnet, and at equal distances from it, likewise unite in a central force acting in the direction from *c* to T′. The magnet is thus impelled in a direction which is at right angles to *c*P, and must therefore continually rotate about P.

Finally, one current may be set in rotation by another, as shown in *pl.* 20, *fig.* 87. The apparatus here figured consists of a copper vessel with an opening in the centre, through which passes a vertical metal rod,

terminating above in a mercury cup. A horizontal wire ending in two balls plays on a fine pivot which rests in the bottom of the mercury cup; at the same time two short vertical wires dip into the acidulated water with which the copper is filled. A current thereby arises, which, for instance, ascends the vertical rod, traverses the horizontal arms in opposite directions, and descends into the acidulated water. If the vessel be surrounded by a wire coil, through which the current is passed, the horizontal wire will be set into rotation by the influence of the circular current.

b. Phenomena of Induction.

An electric current, as discovered by Professor Henry, can beget like currents in a neighboring conductor at the moment of the commencement or cessation of the former, or even by simple approximation or separation: these are called *induced* or *induction currents.* To exhibit these phenomena let two insulated copper wires be wound close together, without conducting contact, on a reel of wood or metal (*pl.* 22, *fig.* 14). Close the circuit of a battery with one of these wires by means of its extremities, *a*, *b*. Simultaneously with the passage of a current through this wire, a current in the opposite direction will be developed in the other wire, provided its extremities, *c* and *d*, are connected, which should be done by means of a multiplier. The multiplier will indicate by the deflection of its needle the existence of the current just referred to; this current will, however, at the instant the primary circuit is closed, be only momentary. On breaking the primary circuit the deflection of the needle will indicate a second current in *cd*, but in a direction opposite to its original one.

These induced currents are capable of producing sparks, shocks, and, indeed, all the phenomena of the primary currents. On bringing the extremities, *c* and *d*, together (*pl.* 22, *fig.* 14), sparks will pass between them; take them in the hands and a shock will be felt at the closing or opening of the primary circuit. If the secondary wires have a considerable length, the intensity of the induction current may even be much greater than that of the primary, for which reason an induction coil is well calculated for producing physiological effects. This is especially the case when the circuit can be closed and opened in very rapid succession, which is practicable by means of the apparatus constructed by Neef and Wagner, *pl.* 22, *figs.* 15 and 16. *Fig.* 15 represents an induction coil, as shown in *fig.* 14; the two wires are generally wound with differently colored silk for the sake of being more readily distinguished. One pole of the battery, the positive for instance, is connected with a mercury cup by a wire, *ab*, this again being connected with a second cup, *d*. Into this latter cup dips one extremity of the inducing or primary coil, which enters the spiral at *e*, again leaving at *f*, and as the extremity, *fg*, is connected with the other pole, the primary current passes from *a* through *b*, *c*, *d*, *e*, *f*, to *g*. The secondary wire enters the coil at *h* and emerges at *i*; its extremities are *hl* and *ik*.

The connexion between the two mercury cups is shown more clearly by *fig.* 16. A metal ring surrounds one of the three pillars supporting the coil; to it is fastened the mercury cup, *d*, as also a copper wire, *mnoc*, which passes under the coil and ends at *c* in a little hammer of platinum. The latter rests on a platinum plate which is soldered to a copper wire leading to the mercury cup, *b*. The upper of these two wires has a thin place at *n*, where it is hammered flat; about this, the wire extremity, *oc*, can move up and down; on lifting the right extremity the hammer, *c*, is raised, and the current of course interrupted. The apparatus itself produces the rising and falling of the hammer. Thus the induction reel contains inside of it a hollow cylinder of soft iron, becoming magnetic whenever a galvanic current traverses the primary coil. It then lifts an iron plate, attached at *o* to the upper wire, and consequently raises the hammer, *c*. The current is instantly broken at *c*, the iron cylinder loses its magnetism, the iron plate, and with it the hammer, *c*, falls, and the circuit is again restored. The cylinder again becomes magnetic, the iron plate is lifted a second time, &c., and the same actions are thus repeated as long as the battery continues to work. The setting screw, *r*, by which the wire *rp* can be raised or lowered, and with it *qp* and *con*, is intended to regulate the distance of the iron plate from the electro-magnet, and with it the rapidity with which the interruptions of the current shall succeed each other. To produce the greatest possible effect on the nerves by the induced current, the metal cylinders, A and B, are fastened to the extremities of the secondary coil. These are to be grasped by the moistened hand, or filled with salt water into which the finger is to be dipped. A constant battery serves best for producing the current.

The mutual influence exerted by the windings of one and the same coil on each other fall properly under the head of induction phenomena. If a simple circuit be closed by a short wire, only a feeble spark will be obtained on opening it; this will nevertheless be much stronger if a long wire is used, and especially if the wire (insulated) be wrapped into a close coil. To take the shock conveniently and in quick succession, the apparatus of Neef (*pl.* 22, *fig.* 15) may be employed, without using the induced or secondary coil. Take two copper wires ending in metal cylinders, and dip the one into the mercury cup *b*, the other into the cup *d*, and grasp the cylinders with the hand. A violent shock will be felt at each opening of the circuit. This is illustrated by *fig.* 17. Here *q* represents the battery; from one pole, when the circuit is closed, the current passes first to the cup *b*, then over the interval, *c*, to the second cup, *d*, and from this through the spiral, *s*, to the other pole. When the circuit is opened at *c*, the shock passes through the human body connecting the cylinders A and B. Finally, the action of the apparatus of Neef may be intensified to a great degree by combining the two coils into one. For this purpose binding screws are attached to the extremities of the secondary coil at *k* and *l*, and into these are to be fastened the extremities of the primary coil, *a* and *g*; *g* into *l* and *a* into *k*.

Electrical currents are produced by magnetism. To show this fact,

wrap a silk wound copper wire about a reel of wood or metal (*pl.* 22, *fig.* 18), whose inner cavity is large enough to receive a magnet, *ab*. The two extremities, *m*, *n*, of the coil are to be connected with the wires of a distant galvanometer. As soon as the magnet is inserted into the cavity of the reel, a deflection of the galvanometer ensues, which immediately ceases, to be renewed in the opposite direction, on the removal of the magnet.

Pl. 22, *fig.* 19, illustrates an entirely different method of producing an electrical current by magnetism. Here *ab* is a strong horse-shoe magnet, *mcn* a horse-shoe electro-magnet, wrapped with a very long coil. Both extremities of the coil are connected with each other at a considerable distance. On quickly approximating the magnet, *ab*, to the legs of the horse-shoe, *m*, *n*, the magnetic fluid in the latter becomes decomposed, and a current arises in the coil which is demonstrated by its deflecting a simple magnetic needle, above or beneath which it passes. On removing the magnet the opposite deflection will be observed. By causing either the magnet or the electro-magnet to rotate rapidly about a vertical axis, so that the pole, *m*, which first stood over *a*, shall stand after a half revolution over *b*, and *n* over *a*, the coil will be continually traversed by currents whose directions alternate.

For conveniently examining the currents induced by magnetism, the *magneto-electric rotating machines*, as constructed by Pixii, Saxton, Clarke, Ettingshausen, and Stöhrer, are very well adapted; in these, except the oldest of Pixii, the magnets are fixed. *Pl.* 22, *fig.* 20, exhibits one of these machines after the construction of Ettingshausen. A and B are the induction coils, wrapped round two cylinders of soft iron. The latter are fastened to the two ends of a horizontal iron plate, whose centre rests on a vertical iron axis, *h* (*fig.* 21). When this is rotated, the two cylinders pass under the poles of a very powerful battery composed of several horizontal horse-shoe magnets; in this manner each iron cylinder acquires an alternately north and south polarity. The coils on the two cylinders are wrapped from one wire of considerable length. One extremity of the wire is fastened by a screw to an iron ring, *g* (*fig.* 22), which is separated by a non-conductor from the iron axis of rotation, *h*; the other is similarly screwed to the iron plate carrying the two cylinders. On the iron axis of rotation another iron cylinder, *h*, is fastened, consisting of three divisions lying one above the other, the middle only of which has an uninterrupted circumference. In the upper part of *h* there are two channel-like depressions diametrically opposite to each other; at the lower end of *h* a segment is cut out, embracing about half the circumference. On each side of the axis of rotation is a small brass pillar with several apertures, provided with binding screws, in which metallic springs for closing the circuit may be inserted. Our figure represents the instrument as arranged to produce powerful physiological effects. In the two upper holes of the right pillar springs are screwed, one of which, during the rotation of the inductor (the entire rotating system), presses continually upon the iron ring, *g*, the other upon the upper surface of the cylinder, *h*. Consequently the circuit is

always closed, an interruption taking place only when the extremity of the steel spring passes over one of the channels, which occurs precisely when the poles of the inductor have just been removed from the magnetic poles. There is, however, another connexion between *g* and *h*, a brass spring being screwed into the left brass pillar, which presses against the middle division of *h*. The metallic conductors, I and R, which are to be held in the hand, are conductively connected, the one with the right-hand pillar, the other with the left. As often now as the galvanic current is interrupted, the shock passes through the body of the individual holding the conductors, and when the rotation is accelerated, the action of the shocks becomes almost insupportable. For producing powerful physiological effects, an inductor must be employed, consisting of a very thin wire wound a great many times about a reel of wood; if for other experiments a current of great quantity but of slight intensity be required, a few turns of very thick wire, wound immediately on the iron nucleus, will be sufficient. The former is called the intensity, the latter the quantity inductor.

Pl. 22, *fig.* 55, represents the magneto-electric machine of *Clarke*, differing from those of earlier construction in dispensing with mercury (as does also the machine of Ettingshausen). Here *e* is the magnetic battery, consisting of vertical horse-shoe magnets resting against four adjusting screws, which pass through the mahogany board, *p*. The battery is bound to the board by two strong brass bands which pass through apertures in it; *f* is the intensity inductor, containing two coils of insulated wire (4500 feet long in Clarke's great machine) wound about the cylinders, *g*, *g*; the beginning of each coil is soldered to the inductor. An iron spring is seen at *i*, which presses by one end against the hollow insulated cylinder, *h*, to which the ends of the coils are soldered. The other end of the spring is fixed in a brass plate fastened to the block *a*; *k* is a four-cornered pillar of brass, which fits in an aperture of a brass band on the left of the block of wood, *c*, and may be fixed in it at any required height. The brass strips on each side of the block *c* must be connected by a copper wire. *m* is a metal spring, held in perfect metallic contact with *k* by the head screw. The remaining parts are intelligible of themselves from the explanation given of the last machine. To produce a shock, the two brass conductors, *n* and *o*, are taken in the hands, previously moistened with salt water; one of the connecting wires is then stuck in the hole of the brass strip to the left of *c*, the other in the hole at the end of the piece carrying the break *k*. On turning the multiplying wheel, *d*, which sets the conductor in motion, the individual having hold of *n* and *o* will experience a severe shock. *r* and *s* are a couple of directors with handles and a piece of sponge to assist in the medical application of the apparatus; the sponge must be moistened with vinegar or salt water for the better conduction of electricity.

Clarke made use of the apparatus represented in *pl.* 22, *fig.* 56, to decompose water, and to collect its elements in separate vessels. Here a^2 is a glass vessel in which are placed two glass tubes, b^2 and c^2. To the right of these are seen two platinum plates immersed in the vessel a^2 under the tubes. To these copper wires are soldered to connect them with *c*. The platinum

wires, *n* and *o*, dip into mercury cups. *Fig.* 57 shows the method of charging a Leyden jar. Wind a piece of copper wire about the external coating of the jar, and connect it with the lower part of the magneto-electric machine; remove the sponge from the director, *n*, and connect its wire with the extremity of the intensity inductor; rotate the inductor with moderate velocity, hold the director by the wooden handle, and let it touch for a moment the knob of the jar until a single spark passes over. On bringing the knob of the jar into connexion with a sensitive gold-leaf electrometer, the latter will indicate a feeble charge of the jar. *Fig.* 58 shows the manner in which the magneto-electric machine can produce rotation. Here *b'b'* is a vertical horse-shoe magnet on a tripod stand, *a'; d'* is a connecting fork; *e'f'* two wire frames with mercury cups above. On pouring mercury into the large vessel, and arranging the wires as in the figure, an uninterrupted rotation will be produced.

Figs. 23–27, *pl.* 22, represent the magneto-electric machine of *Stöhrer*, which, instead of a single magnetic battery, contains three, standing vertically. Quite recently Stöhrer has constructed machines of still larger size, one of them for the university of Dorpat; in these, however, the magnets are horizontal.

c. Rotation Magnetism.

It still remains to mention the so-called *rotation magnetism.* Arago discovered that when a horizontal copper disk is rapidly rotated under a delicately suspended magnetic needle, the latter turns in the same direction about its axis. In his experiments he made use of the apparatus shown in *pl.* 22, *figs.* 52, 53, and 53ª. In *fig.* 52, *h* is a clock-work constructed entirely of copper or brass, excepting some steel pivots; this stands on a firm wooden tripod, and is intended to communicate a rapid rotation to a vertical axis, *x* (*fig.* 53). The latter communicates its motion to a piece of brass, *tt*, separately figured in *fig.* 53ª, on which the copper disks to be employed are fastened. Three vanes on the above-mentioned piece of brass are intended to regulate the velocity of rotation by their greater or less inclination. A four-footed table, *pp'* (*fig.* 52), is set over the clockwork, having an opening in the middle somewhat greater than the rotating disk, but pasted over beneath with a piece of paper. A glass bell, *c* (*fig.* 53), is laid on the table, in which the magnetic needle, *gg'*, is suspended by a silk thread, *f*; the magnet may be raised or lowered at pleasure by the turning of a small axle. The rotation of the disk may also be effected without clockwork. The deflecting force in the rotation of the disk increases with the velocity, but decreases with the distance of the disk from the needle. In disks of other metals than copper, as tin, lead, or zinc, the action is much feebler; it is feeblest with bismuth. It is to Faraday that we owe the explanation of these phenomena by the theory of induced currents.

d. Thermo-Electricity.

Those electric currents are called thermo-electric which are produced by heat, as discovered by Seebeck. If two metal rods are soldered together in two places, so as to form a closed circuit, and the two places of junction have different temperatures, an electrical current arises, and is indicated by the deflection of the needle. In *pl.* 22, *fig.* 11, let *ss'* be a small bar of bismuth, *scs'* a bent strip of copper soldered to the extremities of the first bar at *s* and *s'*; also let *ab* be a magnetic needle playing on a pivot. At the beginning, when both joints have the temperature of the atmosphere, place the apparatus so that the plane of the rectangle, *scs'*, may fall in that of the magnetic meridian: the needle will then be parallel to the edges of the bismuth bar. On heating or cooling one of the two joints, the needle will immediately be deflected to one side or the other. Frequently an elongated rectangle of bismuth and antimony is employed, one of the joints being heated over a spirit lamp, and one of the longer sides of the rectangle held over a magnetic needle. Simple thermo-electric circuits have sometimes the construction of *fig.* 12, *pl.* 22, where *ab* is a bar of antimony or bismuth, and *abcd* a copper wire soldered to it; after heating, one of the joints is held over the needle. The action produced by different pairs of metal is very various. Antimony and bismuth give the most marked results; all metals, however, form a series so constituted that when two of them are formed into a thermo-electric circuit, and heated at one of the joints, the positive current passes at this place from the metal lower in the scale to the higher. This series is as follows: antimony, iron, zinc, gold, copper, lead, tin, silver, platinum, bismuth. The further apart two metals are in this series, the more active is the current they produce.

The most important laws of thermo-electricity are the following: 1. The quantity of the current electricity is the same in all parts of the circuit. 2. The strength of the current is as the thickness of the closing wire, and inversely as its length. To prove this latter proposition we make use of a *differential galvanometer* (*pl.* 22, *fig.* 28). This is distinguished from the ordinary galvanometer in consisting of two coils of equal length, thickness, and conducting capacity. Both wires are wrapped on the same frame. On allowing currents of equal strength to traverse the coils, but in opposite directions, no deflection of the needle will result. In this way we can convince ourselves of the perfect equality of two thermo-electric elements.

To determine the conducting power of different metals, we make use of a very sensitive differential galvanometer, and the two thermo-electric elements represented in *fig.* 29. In the figure, *ab* and *cd* are two cylinders of bismuth, *e* the differential galvanometer, *f* a graduated ruler of from seven to ten feet in length, *g* a platinum wire stretched over this, and *h* a wire of that metal whose conducting capacity is to be compared with that of the platinum. The arrangements are such that the two currents pass through the galvanometer in opposite directions; both circuits, even to the wires *g* and *h*, are perfectly equal. The platinum wire can be shortened at pleasure

until both wires enfeeble equally their proper current. By adjusting the two wires until the needle of the galvanometer stands at zero, it will be found that the conducting capacity of the two wires is directly as their length, and inversely as their cross-section.

If we complete the same thermo-electric current with two different wires in succession, and indicate strength of current, length, cross-section, and conducting capacity of one wire by t, l, s, c, and that of the other by t', l', s', c', then $t' = t \cdot \frac{s'}{s} \cdot \frac{c'}{c} \cdot \frac{l}{l'}$; thus both currents are equal when $s' . c' . l = s . c . l'$. From this we may calculate the length, l', which a wire of cross-section, s', and conducting capacity, c', must have, to present the same resistance to an electric current as is presented by another whose cross-section is s, conducting capacity c, and length l. Copper is generally taken as the standard with which other metals are compared. Determinations of this character are readily made by means of the apparatus shown in *fig.* 30. Here *rr* is a thermo-electric element to which are soldered two copper wires; these are immersed in the mercury cups *a* and *b*, which are connected by a piece of wire, *bca*, and are united besides by a second wire, *adb*.

An unalterable thermo-electric current to be used in comparing its action on the magnetic needle with the magnetic action of the earth can best be obtained by connecting copper and bismuth. This combination should consist of a bismuth cylinder (about twenty millimetres in diameter, the horizontal part 150 millimetres long, and each vertical extremity fifty millimetres), and a copper wire of one millimetre in diameter and twenty metres in length. If one place of junction be brought to 32° F., and the other to 212° F., this circuit will always give the same current. The copper wire is wrapped in twenty windings on a frame, shown in section by *pl.* 22, *fig.* 31, and from above in *fig.* 32. The needle which plays on a pivot in the centre of the frame is invisible when it is parallel to the windings; for this reason a light plate is fastened to each one on which a mark is attached.

By connecting several thermo-electric currents in one pile, or compound battery, the action will be decidedly strengthened when the first, third, fifth, and seventh places of junction are heated, and the intermediate joinings left cool, or the reverse. For investigating the laws of such piles, an apparatus, as figured in *pl.* 22, *figs.* 33 and 34, may be used, consisting of 8, 24, or 32 elements of bismuth and copper, as shown in *fig.* 35. By means of glass vessels alternately filled with ice and hot water, the places of junction may be kept alternately at 32° and 212° F. A magnetic needle suspended from a silk thread, and held over the middle of a copper element, shows by its oscillations the strength of the electric current. A *Nobili pile*, represented in *pl.* 19, *fig.* 37, is well adapted to produce a deflection of the needle of an interpolated thermo-electric multiplier (differing from the common one in the smaller number of its windings and the greater thickness of its wire). This pile is composed of twenty-five to thirty very fine needles of bismuth and antimony, about two inches long,

which are so combined that all the even soldered joinings are on one side, and all the uneven on the other. The intervals between the single bars being filled by some insulating substance, the whole forms a compact bundle. That one of the two metals with which the pile ends is in conductive connexion with the point x, the other with y, so that these two points are to be considered as the poles of the battery.

METEOROLOGY.

Plates 23—29, and Plate 47 in part.

Meteorology, an important and interesting branch of Physics in its more copious sense, on account of its extent is more usually treated of separately. This science has for its object the investigation and explanation of the physical phenomena which occur in the atmosphere, including all those known as *meteors*, not restricting the term to its more usual acceptation of shooting-stars. Meteoric phenomena may be distributed into various classes, including aerial (winds), watery (water spouts, &c.), optical, fiery, and electrical. The zodiacal light, and many of the shooting-stars which are sometimes embraced under the head of meteorology, in all probability do not belong here, as perhaps not falling within our atmosphere.

A part of meteorology, and one not readily separated from it, is formed by climatology or the theory of climate, by this being meant the geographical part of meteorology, or that which investigates the geographical distribution of those changes and phases of weather, constituting what is called the climate of a place. However great our interest in this subject of the weather and atmospheric phenomena in general, it cannot yet be denied that meteorology is behind all the other departments of physics. This is caused by the great variety and complexity of most of the phenomena, but it is principally because we have not yet been able to collect a sufficient body of laborious, accurate, and long-continued observations from all parts of the earth to make our deductions. Much is due, however, to the labors and researches of A. Von Humboldt, Schouw, Dove, Schübler, Kaemtz, Sabine, Reid, Piddington, Meyen, Redfield, Espy, Hare, and others.

1. *Chemical Constituents of the Atmosphere.*

The principal components of the atmospheric air are oxygen and nitrogen mixed nearly in the proportion of one to four. To speak more accurately, 100 parts of air contain twenty-one parts oxygen and seventy-nine nitrogen by volume, and twenty-three parts oxygen and seventy-seven parts nitrogen by weight. This ratio is to be considered as constant, and

remaining the same in all countries and seasons, without being affected by temperature, moisture, atmospheric pressure, or elevation above the level of the sea. Even in the vicinity of swamps, or in places where large bodies of men have congregated, as in churches, theatres, &c., the proportion of oxygen is the same; whence it follows that the unwholesomeness of such places lies not in the deficiency of oxygen, but in the predominance of some other substance.

Besides oxygen and nitrogen, and the constantly present watery vapor not reckoned as a constituent, there are other ingredients found in the air, some of which are quite variable in quantity. The first of these is *carbonic acid gas*, produced by the respiration of man and animals, putrefaction, fermentation, combustion, and other processes, and occurring everywhere, at least on land. The amount, according to Humboldt's observations, is greater in summer than in winter; according to Saussure, greater at midnight than at noon; greater on mountains during dry, windy weather, than in plains when the air is still and damp. Dalton's observations determined the average amount to be one twentieth, and this was confirmed by Saussure's experiments made in a meadow near Geneva in 1816–28, who estimated it at 0.049, or nearly one twentieth. The air above the ocean appears to contain but little carbonic acid gas.

Another ingredient of the air is *ammonia*, a gas generated during the putrefaction of animal matter. This has but recently been detected by Liebig, who found it in snow or rain-water. Rain-water always contains ammonia, and in summer more abundantly than in winter or spring.

The third variable ingredient is *hydrogen*, hitherto only found as a constituent in the vicinity of volcanoes and swamps, although in the decomposition of animal and vegetable substances, and in the oxydation of metals, considerable quantities must be set free. The supposition of some, that this gas, on account of its extreme lightness, ascends in the atmosphere and forms its confines, is very improbable, as it diffuses itself readily through the pores of other gases. At a height of 20,000 feet Gay Lussac found no appreciable trace of hydrogen.

2. *Distribution of Heat on the Earth.*

The alternation of heat and cold, and the unequal temperature at different places on the earth's surface, unquestionably constitute the most important and remarkable changes in the condition of the atmosphere. The sun is to be considered as the principal cause of the heating of the earth's surface and of the air, his rays producing an effect proportional to the greatness of the angle of their incidence, although this effect may be modified by the density of the strata and the absorbing power of terrestrial objects. It is necessary, however, to consider the double motion of the sun (the diurnal and the annual) in its meteorological relations. In the diurnal motion of the sun, he stands highest in all places

at noon, and at this time, or a few hours later, the heat is generally the greatest. Nevertheless, the height of the noon-day sun is neither the same at the same place throughout the year, nor the same at all places on the same day. It is only between the tropics that the sun at noon stands vertically over head, and this only once in the year at each tropic, and twice at the equator. The deviation from perpendicularity during the rest of the year is, however, so slight, that this region (between 23° 28′ N., and 23° 28′ S. lat.) is naturally the warmest on the earth, deserving the name of *torrid zone.* In those countries of the earth lying about the poles and within the polar circles, the sun is above the horizon for a day, or even for days, weeks, or months (six months at the poles), during a certain portion of the year, and below it for equal lengths of time during another portion, the length of these uninterrupted days or nights increasing towards either pole. Nevertheless, as the sun in these regions can never ascend far above the horizon, his rays must always fall very obliquely in the two *frigid zones.* The rest of the earth's surface lying between the tropics or polar circles, or extending from 23° 28′ to 66° 32′ north and south latitude, forms the two *temperate zones,* north and south. These include more than one half, or .52 of the entire surface of the earth; the two frigid zones about a twelfth, or over .08; and the torrid zone almost .40.

The two temperate zones have four seasons (spring, summer, autumn, and winter), these commencing at different times in the two zones. For the north temperate zone spring commences March 21, when day and night are everywhere equal; summer on June 21, when the days are longest; autumn on September 23, when day and night are again equal; and winter on December 21, when the days are shortest. The seasons of the south temperate zone are precisely the reverse of these just mentioned, summer and spring of one answering to winter and autumn of the other. From March 21st to September 23d, the sun is north of the equator, and traverses from west to east the six signs, Aries, Taurus, Gemini, Cancer, Leo, Virgo; in the rest of the year he passes through the remaining signs, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, and Pisces. He is in the equator March 21st and September 23d, at which time places on the equator have him in the zenith. (See *pl.* 23, *fig.* 1, where the dotted circle indicates the equator; the circle intersecting it in two points, and marked with the signs of the ecliptic, the ecliptic; and the irregular curved line, the temperature in the course of the year. This figure is known as Howard's diagram.)

As a general rule, the further from the equator the greater is the difference between the summer and winter temperature; even in the vicinity of the polar circles the summer may be very hot. This depends upon the influence exerted by the unequal length of days. This difference is very slight at the tropics, where the inequality of days is inconsiderable. Thus at the equator the days and nights are equal throughout; at a latitude of $8\frac{1}{2}°$ the longest day is twelve and a half hours; at $16\frac{3}{4}°$ it is thirteen hours, or two hours longer than the shortest day; and at the

tropics itself, or 23° 28′, this maximum is about thirteen and a half hours, or three hours longer than the minimum. This difference is far more considerable at higher latitudes, so that the sun may, in a measure, make up by the length of time he remains above the horizon for what he loses by the obliquity of his rays. This duration of the longest day amounts to :

14	hours at	30° 48′	20	hours at	63° 23′
15	"	41° 24′	21	"	64° 50′
16	"	49° 3′	22	"	65° 48′
17	"	54° 31′	23	"	66° 21′
18	"	58° 27′	24	"	66° 32′.
19	"	61° 19′			

The longest day, with a slight allowance for refraction, is equal to the longest night of a place, and the shortest days and nights are found by subtracting the hours of the above table from twenty-four. The astronomical determination of the seasons is not quite appropriate for meteorology, this rather requiring spring for the northern hemisphere to begin March 1st ; summer June 1st ; autumn September 1st ; and winter December 1st. The case is just the reverse in the southern hemisphere, mid-winter there corresponding to mid-summer here.

In the torrid zone the year is divided into two seasons, the dry and the wet or rainy. The latter commences when the sun at noon approaches the zenith, and therefore at different times of year on the opposite sides of the equator. The previously clear sky becomes clouded, and rainy weather sets in, which continues with little interruption for several months. In the interior of Africa each of these seasons lasts just six months. In the frigid zone the year is likewise divided into two seasons, winter and summer, which yet are of very unequal duration, the former having the preponderance in proportion to the proximity of the pole.

Nevertheless, the heat experienced at a given place, at a given time of the year or day, does not depend on the geographical position of the place or the situation of the sun alone, but also on many other circumstances. It is therefore of great interest to ascertain the variation of temperature of a place by continued and frequent thermometrical observations. If the thermometer, which for this purpose must be placed in the open air, and protected from the direct rays of the sun, and from radiation, reflection, &c., be examined hourly, it will be found that the minimum of daily temperature generally takes place fifteen or twenty minutes before sun-rise, the maximum some hours after noon, and later in summer than in winter ; in summer between two and three o'clock, in winter between twelve and one. The mean temperature of the twenty-four hourly observations is very nearly that of the highest and lowest temperature, or that of several corresponding hours in the morning and evening, as four and ten in the morning and evening. The temperature between nine and ten A. M., that at sunset, and that at eight P.M., is also very near the mean.

Self-registering or *maxima* and *minima thermometers* are used to ascertain the highest and lowest temperatures in a given time, without the

necessity of constantly observing the instruments. The self-register invented by Rutherford consisted of two thermometers in the same frame, with their tubes horizontal, one of these being filled with mercury, the other with colored alcohol. In the tube of the former is a cylindrical steel pin, which is pushed forwards by the expansion of the mercury, but does not return with its contraction, thus registering the highest temperature. In the tube of the alcohol thermometer is a fine glass rod, somewhat thicker at the extremities, which retains its place when the liquor expands, but is retracted with the latter on its contraction by a diminution of the temperature. The bulbs of the two thermometers lie in opposite directions on the stand. To adjust the apparatus for a fresh experiment it is to be gently inclined, the alcohol bulb uppermost, and slightly tapped. The steel pin slides down to the top of the mercury, and the glass rod to the end of the column of spirit. These indexes are now so placed that an increase of temperature causes the steel to advance, its diminution producing the retraction of the glass. This instrument is not well calculated for travellers, being principally adapted to fixed stations, and is quite inapplicable to ascertaining the maxima and minima of temperature in mines, caves, Artesian wells, depths at sea, &c. The description of such an instrument, invented by Magnus, and called the geothermometer, will be found under the head of *Mining*.

The mean temperature of the month is obtained by taking the mean of all the mean daily temperatures; and that of the year will be the mean of the mean monthly temperatures. The maximum of cold occurs about the 14th of January; that of heat about the 26th of July. The mean annual temperature is experienced about April 24th and October 21st. At Paris, during the interval from 1665 to 1823, the coldest day fell principally in the second half of January. At Frankfort on the Maine, the average of twenty years' observations gave January 15th as the coldest and July 22d as the warmest days, the days of mean annual temperature occurring about April 8th and October 18th. In the torrid zone there are two maxima and two minima in each year. The former occur at the equator about April 20th and October 20th; the latter about January 20th and July 20th. The observed maxima and minima differ in Surinam by 52°, in Pondicherry by 73°, and in Cairo by 88°F. This difference, again, is at Rome 111°, at Paris 142°, at Prague 145½°, at Moscow 159° at St. Petersburgh 161½°, and in Greenland 165°, which agrees with what we have already said on the subject. The highest observed temperature in the shade and open air does not exceed +113°F.; the minimum is about —70°F.

The mean temperature of a place is obtained by taking the mean of as many annual means as possible; this may, however, be approximately obtained from observations of a few years, the mean annual temperatures of a place differing little from each other. Thus, the mean temperature of Moscow and St. Petersburgh amounts to 37½°—39°F., of Drontheim to 40°, of Stockholm and Christiana to 41°—43°, of Königsberg to 43½°, of Breslau, Dantzig, and Copenhagen, 44½° to 45½°, of Berlin, Hamburg, and Edinburgh, to 46½°—48°, of Warsaw, London, Dublin, Prague, and Frankfort on the

Maine, 48°—50°, of Manheim, Vienna, Paris, Amsterdam, to 50° —52°, of Brussels, Hague, and Turin, 52°—53½°, of Marseilles, Pekin, to 53½°—55½°, of Mailand, Bordeaux, to 55½°—57°, of Rome to 60°, and of Lisbon and Palermo to 61°—62½°F. *Pl.* 29, *fig.* 2, contains a graphical representation of the mean annual temperatures in the cities of Berlin, Stockholm, and Copenhagen, from observations made during the years 1758—1834; *fig.* 3 does the same for a period of ten years; *fig.* 4 is an exposition of the range of the hourly mean yearly temperature for two places in the north temperate zone, namely, Padua, and Fort Leith near Edinburgh. In the figures the degrees are given by Centigrade.

The first clear view of the distribution of heat over the surface of the earth was given by Humboldt, by means of his *isothermal lines*, lines connecting all those places whose mean annual temperature is the same. These are shown in *pl.* 29, *fig.* 1, as laid down on Mercator's projection, with the thermometrical degrees by fives of Centigrade; this projection also exhibits the proportion of rain. That isothermal obtained by connecting the hottest places of the earth, whose mean temperature is about 82½°F., is called the *equator of heat.* This is far from coinciding with the terrestrial equator, and lies almost entirely in the northern hemisphere. The curvature of the isothermals, which, within the tropics, are nearly parallel, becomes considerable in proportion as we remove from the equator. In the vicinity of the north pole, the isothermals probably form two separated and closed curves, whose centres may be taken as the coldest points in the northern hemisphere, and called *poles of cold*, after Brewster; neither of these coincides with the north pole, but one lies in Asia and the other in North America.

Nevertheless it is not sufficient to know the mean annual temperature of a place to be acquainted with the distribution of heat in the different seasons, since places on the same isothermal line do not necessarily present the same climatic relations. Thus, Edinburgh and Tübingen have the same annual temperature of 47½°F., yet the mean winter temperature of Edinburgh is 38.4°F., and that of Tübingen 32.3°F. A good idea of the distribution of heat between summer and winter is obtained by constructing a map, in which all places of equal summer and all of equal winter temperature shall be connected by curves; the former are called *isotheral*, and the latter *isocheimenal* lines. Neither of these lines is parallel to the *isothermals.* The isocheimenal line of 32°F. passes through south-western Norway, Denmark, Bohemia, Hungary, Bessarabia, and the Crimea. The isotheral of 68°F. passes from the mouth of the Garonne, over Strasburg and Wurtzburg, to Bohemia, through the Ukraine, north from the Caspian Sea, &c.

The climate of a country, besides its geographical position, depends upon many circumstances, as the proximity of the sea and of mountain ranges; the peculiarities of the soil, &c., exercise a great influence. We distinguish a land and a sea (island) climate: the land is warmed and cooled more readily and more quickly than the sea. For this reason the daily and annual variations of temperature are much more considerable in the interior of continents than over the sea, on the coast, and over islands and peninsulas, which have a more constant climate. Tobolsk and Irkutsk, in the interior

of Asia, have summers like those of Berlin ; to these, however, follow severe winters, in which the mean temperature of the coldest month amounts to from —½°F. to — 4°F. Such a continental climate may justly be called excessive. The unequal distribution of land and water produces indirectly an unequal heating in different places, by influencing in a great measure the direction of wind and ocean currents, which diffuse both higher and lower temperatures. Europe owes her proportionably mild climate to three causes: 1. To her peculiar shape, her coast being broken to an extraordinary degree, thus producing a very long outline. 2. To the character of the land south of her, the greater part of Africa being barren and sandy, and at the same time very hot, thus giving rise to incessant currents of warm air. 3. To the gulf stream. This gulf stream comes from the gulf of Mexico, where the temperature of the water amounts to nearly 88°F., coasts the peninsula of Florida, follows the coast of North America to 39° or 40° N. L., turning off then in a north-easterly direction towards Europe, which owes its freedom from polar ice to the fact that the gulf stream tempers the waters on its coasts. Northern Asia has a very cold climate compared with Europe. In America, the climate in the interior and on the eastern coast is much more severe than on her Pacific shore, cold currents from the north traversing the former, carrying the polar cold into more southern regions. Thus, at Nain in Labrador, on the eastern coast, the mean annual temperature is about 24°F. ; at New Archangel, on the western coast, nearly in the same latitude, this same mean is about 44½°F. The mean summer temperature in the former place is scarcely 43°F., that of the latter about 57°F. As a general rule, the eastern coast of a continent is colder than the western, a fact which will be explained in the section on winds. The southern hemisphere is considerably colder than the northern ; in the former the polar ice reaches 20°—30°, in the latter only 9° from the pole : ice not rarely occurs in the former at a latitude of 31°. In the new world the mean temperature increases more rapidly with increasing latitude than in the old.

The temperature of the ground is often remarkably different from that of the air, sometimes higher and sometimes lower, according to circumstances. The mean temperature of the earth's surface agrees very nearly with that of the air at a mean latitude, and is generally indicated by the temperature of springs ; at higher latitudes the mean temperature of the ground is higher, and at lower latitudes it is lower than that of the air. The temperature of the ground from the equator to the pole diminishes the faster as we approach the parallel of 45°. At a slight depth the variations of temperature are much less than at the surface, and at still greater depths there is no variation whatever, a constant temperature existing, but little different from the mean annual temperature of the place. The depth at which all annual variations of temperature vanish entirely, varies in different places ; in the torrid zone it amounts to only one foot; in the temperate, as in France, Germany, &c., this depth is from sixty to seventy feet ; even here, however, the diurnal variations vanish at a depth of from one and a half to three feet. The temperature of the earth increases regularly with increasing depth, this

increase on an average amounting to about one degree for every forty or fifty feet, although the exact law of this increase has not yet been determined. Its cause is to be found in the original heat of the earth, which, radiated from the surface, is still retained in the centre. Should the heat increase in the same ratio with increasing distance from the surface, water would boil at a depth of 10,000 feet, and granite would melt at a depth of five miles; consequently, the heat at the centre of the earth must be so great as to melt even the most refractory bodies. The reason that this heat is not sensible at the earth's surface is to be found in the badly-conducting character of her crust.

The opposite phenomenon, a decrease of heat, is observed as we ascend in the air, the higher layers being colder than the lower; nevertheless, the diminution of temperature is not exactly proportional to the elevation. As the lower strata of air become heated by contact with the earth, they ascend, and expanding as they ascend, a great amount of heat is rendered latent; the temperature is thus necessarily reduced. On high mountains, particularly those of Central and South America, this decrease in temperature is well shown by the change in the vegetation as we ascend. Thus on the slope of a single mountain we may pass in comparatively few hours from the climate and vegetation of the tropics to the stunted flora and icy temperature of polar regions. The precise diminution of temperature depends upon the character of the particular mountain on which it is observed. The variation of temperature experienced in ascending in a balloon differs from that on high mountains, the latter absorbing heat during the day, which is again radiated or transmitted to the incumbent layers, thus elevating the temperature. Elevation and other circumstances being equal, it is warmer on elevated planes and connected mountain ranges than on isolated mountains; on the former the periodical variations of temperature are also greater. Gay Lussac, in his celebrated balloon ascension, found that the temperature diminished on an average about one degree Fahrenheit for every 615 English feet of ascent. In the Cordilleras the elevation necessary for a decrease of one degree F. in temperature was about 300 feet (French) from 0 to 3000 feet of elevation; 444 feet from 3000 to 9000; 228 feet from 9000 to 12,000; and about 306 feet from 12,000 to 15,000: the average of all was thus about 318 feet to the degree. From a comparison of the temperature of Geneva and the St. Bernard, an elevation of 335 feet was found to correspond on the average to a decrease of one degree of temperature; nevertheless, this ratio varies in different months very considerably. In other regions of the Alps the ratio is less than that just mentioned.

At a certain height above the level of the sea, varying with the latitude, a temperature prevails so low in degree, that ice and snow once formed do not melt, but remain throughout the year. This *snow line*, or the greatest height up to which snow can melt, is higher as we approach nearer the equator. The following table of snow lines is taken from Humboldt; the elevations are in English feet.

Mountain Chains.	Latitude.	Elevation.
Cordilleras of Quito	0°— 1½° S.	15,730
" Bolivia	16 —17¾ S.	17,060
" Mexico	19 N.	15,030
Himalaya { Northern side	31	16,940
Himalaya { Southern side	31	12,470
Pyrenees	43	8,950
Caucasus	43	10,870
Swiss Alps	46	8,760
Carpathians	49	8,500
Altai	50	6,395
Norway { Interior	70	3,512
Norway { Coast	71½	2,302

In illustration of the subject let the reader refer to *pl.* 23, *fig.* 2, where NESQ is the earth's surface, CDEF the outer boundary of the atmosphere, ANBS a section of the limit of perpetual snow, which, apart from single irregularities, attains its greatest height, AE and BQ, in the equatorial regions, coming down to the surface of the earth near the poles. It is a great error to suppose that the snow line always lies in those regions where the mean annual temperature is 32° F.; it almost always lies higher than this. Its altitude depends principally upon the temperature of the hottest month, and also upon the local moisture, the shape of the mountains, &c., and is far from increasing regularly towards the equator. Hence it not rarely occurs that the snow line is higher on one mountain than on another which lies nearer the equator. Thus in Norway this line lies proportionably very high, being 400 feet higher at a latitude of 70° than in the islands 5° further south. As a general rule the snow line lies lower on the coast of a country than in its interior. Under the equator the snow line of South America reaches the height of Mont Blanc; fourteen to eighteen degrees south of the equator in the Chilian Andes, according to Pentland, it rises 2500 feet higher than under the equator, as at Quito, Chimborazo, Cotopaxi, and Antisana. The reason of the lesser height of the snow line on the north side of the Himalaya than on the south (see preceding table) is to be found in the deposit of immense quantities of rain and snow on the south side, from the atmosphere charged with the vapors of the Indian Ocean, far less falling from the dry air of the northern declivity. Even in the Alps there is a great difference in this respect between the south and north sides. Saussure observed that the great fields of snow in the Alps were capable of depressing the snow line by as much as 600 feet. In some cases these curves in the snow line are very numerous, as shown in *pl.* 23, *fig.* 3.

While we have a means of examining the lower snow line, owing to its accessibility, we have none for the upper limit, because the mountains of the earth do not lift themselves into those regions where, on account of the too great rarity and dryness of the air, snow no longer presents itself. The term *upper snow line*, as used by some authors, is not to be understood in

the sense just referred to. It simply means the limit of perpetual snow; while the *lower snow line* refers to a limit at which snow sometimes continues for some years.

But little change in the temperature of springs is observed with the different seasons, the range in the temperate zones being rarely more than from 1°—3°F. Their highest temperature in the northern hemisphere occurs in September, their lowest in March. In the torrid zone their mean temperature is somewhat lower, in the temperate somewhat higher than that of the air. Springs coming from great depths have, however, a much higher temperature, as shown by various salt and mineral springs, and artesian wells.

As already observed, the daily variations of temperature are much slighter at sea than on land. In the torrid zone, the difference between the daily maximum and minimum, at the highest, amounts to 2°—4°F.; in the temperate zone to 3°—6°F. In the torrid zone, the temperature of the sea decreases with the depth; while at the surface this may amount to from 80°—88°F., at great depths it may be only 35° or 36°F. This coldness of the lower strata of the ocean waters, according to Humboldt, causes currents which lead the polar waters towards the equator.

3. *Atmospheric Pressure.*

The amount of pressure exerted by the atmosphere at any one place is measured by the height of the mercury in the barometer. Temperature, however, also affects this height, the mercury rising slightly with increase of heat, and sinking with cold, independently of any change in the pressure of the air. To compare different observations, therefore, it becomes necessary to reduce them to some standard of temperature, this being assumed at 32°F., or the freezing point. Now mercury expands .0001 of its bulk for every degree above 32°F., therefore all that is necessary to make the required reduction is to subtract the ten-thousandth part of the observed altitude for every degree of Fahrenheit above 32°. Application may also be made of the formula $h - (t - 32) \times h + .0001 =$ the corrected height, where $h =$ the observed height of the mercurial column, and $t =$ the temperature at the time of observation. Allowance must also be made for the expansion of the attached scale, unless this be of glass, brass, or other metals expanding nearly as much as mercury. A third correction must be made for capillary depression of the mercury. For the sake of avoiding tedious calculations, tables of these corrections required have been constructed.

The barometer exhibits incessant variations in altitude, distinguished into diurnal and annual. Of these the former are much less conspicuous in the temperate zones than in the torrid. There the amplitude or greatest extent of daily variation is, in Quito, 2.82, in Guinea 2.44, in Cumana over $2\frac{1}{3}$, in Jamaica 1.45, in the Canary Islands 1.10, in Rome 0.70, in Paris 0.76, in London 0.38, and in St. Petersburg only one fifth of a millimetre. In

general, however, from observations made on both hemispheres, from 0° to 79° of latitude, and to a height of 12,000 feet, it has been found that the barometer twice reaches a maximum and twice a minimum every day. The maxima occur between $8\frac{1}{2}$ and $10\frac{1}{2}$ A. M. (on an average at 9h. 37m.), and between 9 and 11 P.M. (average 10h. 11m.); the minima between 3 and 5 A. M. (average $3\frac{3}{4}$ A. M.), and between 3 and 5 P. M. (average 4h. 5m.). These hours of highest and lowest barometer stand in the course of a day, where the rise of the mercury exceeds the fall, or the reverse, are called the hours of turn; they fall nearer noon in winter than in summer. In winter, and during the rainy season of the tropics, the daily variations are least, and greatest in April. On high mountains in the torrid zone, the diurnal variations are much less than in the low lands. Here there is not, as a general rule, a twofold rise and fall of the barometer, but only one daily maximum and minimum; the hours of turning also lie nearer noon. The daily mean value is observed, on an average, about ten o'clock in the morning and nine o'clock in the evening.

On taking the mean of the hourly variations of the barometer for every month, it will be found that in June, July, and August, the barometer is generally higher in the morning and lower in the afternoon than the mean annual temperature, while the opposite is the case in October, November, and December. The mean monthly barometer height varies from one month to another, and this more conspicuously in the temperate than in the torrid zone; it is higher in winter than in the other seasons. The accidental, or not periodical variations, are considerably greater in winter than in summer, and this the more with the distance from the equator. Lines connecting places of equal annual variation of the barometer are called *isobarometrical lines*. These are not parallel to circles of latitude, but ascend, for instance, northwards from the eastern coast of America towards Europe and Asia, diverge in the interior of the continent of the old world more and more from the equator, and then sink down again.

The absolute mean barometric condition of a place, like the mean temperature, is obtained by taking the mean of as many mean annual barometric heights as possible. This depends not only on the level above the sea, but also on the geographical position in longitude and latitude. For this reason the mean barometer height is not, as formerly supposed, the same everywhere at the level of the sea. It increases from the equator in either direction, attaining its maximum between 30° and 40° of latitude, and then decreasing to between 60° and 70°. It appears again to ascend within the polar circle. From the equator to 15° of latitude, the mean height of the barometer at the level of the sea amounts to 337–338 Paris lines (29.65 to 29.74 English inches), it then increases to 339 lines (29.83 inches), afterwards decreasing. The mean height of the barometer at the level of the sea also depends to a certain extent on the longitude, at equal longitudes and seasons being greater in the Atlantic than in the Pacific, the difference being on the northern hemisphere 1.3 lines in winter and 1.8 lines in summer, and in the southern 0.3 lines in summer and 1.6 lines in winter. The following

table exhibits the mean height of the barometer at different places situated near the sea:—

Equator . . .	0°	336.5‴	Marseilles . .	43 N	337.4‴
Christiansborg .	5½ N	336.9	Triest	46 "	337.8
Cumana . . .	11 N	336.3	Brest	48 "	338.5
Callao	12 S	337.2	Paris	49 "	337.5
Madras	13 N	337.3	London . . .	51½ "	337.2
Peru	17 S	337.35	Edinburgh . .	56 "	336.1
St. Thomas . .	18 N	337.1	South Sea . .	57½ S	336.4
Rio Janeiro . .	23 S	338.7	Stockholm . .	59 N	335.9
Macao	22 N	338.2	St. Petersburg .	60° "	337.2
Madeira . . .	32½ N	339.1	Reikiavig . . .	64 "	333.4
Cape of Good Hope	34 S	338.2	Gothaab . . .	64 "	331.5
Naples	41 N	338.2	Spitzbergen .	75–78 "	335.5

Erman assumes the reduced mean barometer height at the equator at 337.2‴; at a latitude of 25° he calculated the maximum to be 338.7; at a latitude of 45°, to be 337.6‴. (The line, indicated by (‴), is .088 of an English inch.)

The cause of the above-mentioned variations of the barometer is to be found in the unequal distribution of heat on the earth, this varying incessantly. Heated air being lighter than that which is cooler, causes a difference in atmospheric pressure, as indicated by the barometer. Suppose the air over a certain region to become heated: the column expands, and rising higher than the surrounding atmosphere, is diffused laterally. Under this column, then, the mercury will fall, rising under the colder surrounding atmosphere, over which the excess of the ascending column had spread.

From what has just been said it is clear that the falling of the barometer, at least in Europe, is generally connected with a rise of the thermometer, and vice versâ. This same connexion between the rise and fall of the two instruments takes place in the tropics, for which reason the barometer may be called a differential thermometer, from its indicating the difference of temperature between neighboring great tracts of country. The barometer may, however, rise and fall considerably without any change in the thermometer, and both instruments may rise or fall together. The regular changes of temperature in the course of the day have little influence on the barometer. The maximum of the irregular variations of the barometer occurs when the yearly temperature is the least; the minimum a short time before the occurrence of the highest temperature.

The barometer, it is well known, is sometimes used to predict the weather. As a general rule, the barometer by day sinks before a rain, and ascends during the rain. It exhibits more or less agitation during storms, and from this we may draw conclusions with respect to such storms, and even sometimes predict them; yet the proposition that the barometer must stand very low during storms is not always true. During the storm of Dec. 14, 1786, on the Isle of France, the barometer fell nearly eight lines in four hours, and ascended again ten and a half lines in two hours. During the hurricane on Sept. 21st, 1819, at St. Thomas, it fell four lines in four hours,

and again ascended more than five lines in three quarters of an hour. From Humboldt's observations the hurricanes between the tropics are not accompanied by so great a depression of the barometer as is generally supposed.

4. *Of the Winds.*

All motions of the atmosphere, or aerial currents, are known by the general term *winds*. These almost always arise from an unequal heating of the earth's surface and of the incumbent air, although other causes may occasionally operate, as, for instance, the sudden condensation of watery vapor in the atmosphere. The theory of winds is well illustrated by an experiment as figured in *pl.* 23, *fig.* 62. If, during winter, the door of a warm room leading into an apartment or passage-way that is not heated, be slightly opened, and a burning candle held to the upper end of the crevice, the flame will be driven outwards, and thereby demonstrate the existence of a current of heated air from the upper part of the room. About the middle of the opening the flame will be vertical, owing to the absence of both an inward and outward current. At the bottom, again, a current will be again sensible, consisting of the colder external air pressing into the room to supply the loss occasioned by the upper outward current. This air then, after entering the room, becoming heated, and therefore lighter, ascends and passes out at the top again. Precisely in the same manner the air in the warmer regions of the earth ascends and flows over the colder, while that from the surrounding colder regions flows in from below.

To determine the direction of winds at the surface of the earth, weather-cocks or wind-vanes are used. These consist of a flat thin piece of sheet iron or other material, of an appropriate shape. This is placed in a vertical plane, and turning on a vertical axis passing through its centre of gravity. The surface of the vane on one side of this axis must be greater than on the other, so that when struck by the wind it may have a determinate direction. Thus we may construct the vane in the shape of an arrow broadly feathered; the barb will then point in the direction from which the wind comes. This direction is generally estimated by the eye, but may be obtained more accurately by fixing under the vane a series of rods, connected in a frame-work, and pointing to the four quarters of the horizon. Each rod has a letter at its extremity indicating this direction as N., S., E., W.; sometimes there are four others to indicate the N.W., S.W., N.E., S.E. points of the compass. A very convenient construction of the vane is to have its axis passing down through the roof into a chamber. On the lower end of the axis is to be fixed an index, which shall rotate in a circle marked with the directions of the wind. This index, turning simultaneously and equally with the vane, will always tell the direction of the wind without the necessity of going outside of the house. It should have been before mentioned, that vanes, to be of scientific value, must be as much as possible free from the minor currents produced by local obstructions; their elevation,

then, above surrounding objects, is absolutely necessary. Self-registering weathercocks, called *anemometers*, or *anemographs*, have also been constructed by Landriani, Parrot, Traill, Osler, and others, where the direction of the wind during the twenty-four hours is traced directly on paper without the necessity of an attendant.

Besides the direction of the wind it is necessary to consider its velocity and strength. The simplest method of ascertaining the velocity of wind is to make use of an apparatus similar to that employed in ascertaining the velocity of a current of water. Thus, a light body, as a piece of paper or a downy feather, &c., may be let loose into the air, and the distance traversed in a given time noted; this is, however, entirely inapplicable in high winds, owing to the irregularity of the motion, and the difficulty of properly regulating the experiment. Some have endeavored to use the passage of the shadows of clouds over the surface of the earth to ascertain this velocity, but this method is not very applicable, owing to the uncertainty of the path and the small portion measurable by a single observer. The most satisfactory and generally used method is to ascertain the perpendicular pressure of the current against an opposed surface of known area, assuming that the force of the wind is a consequence or a function of its velocity. Contrivances for measuring the force of the wind are called *anemometers*, in the restricted sense of the term. They have been proposed and constructed in great variety. The first method proposed was to allow the wind to strike against a vertically depending disk or plate, and to determine its force by the angle through which the plate was lifted. This idea was the basis of the anemometer of Pickering and Oertel. In Dalberg's construction, the disk, instead of depending, was erected vertically on a hinge, and kept to the wind by a great vane. More recently, Parrot has proposed instead of a disk to take a hollow ball, which, suspended freely by a rod, shall be raised by the wind, the angle of elevation being measured on an attached quadrant, and from this angle the force of the wind determined. One of the oldest and simplest anemometers is that of Bouguer, consisting of a square plate fastened to a four-sided rod. This rod fitted in a hollow four-cornered parallelopipedon, and pressed against a spiral spring contained in it. The plate being made to face the wind, the amount of pressure exerted on the spring was measured by an index. This instrument has recently been much improved by Beaufoy.

In another class of anemometers the wind turns wheels or vanes: to these belong those of Christiani, Wolf, Leutmann, and others, the ingenious self-registering anemometer of Michael Lomonosow, and the hydrometric vane of Waltmann. By means of this latter instrument the velocity of running water may be ascertained as well as that of the wind. It consists of a small windmill, to whose axis an endless screw is attached, which catches in the teeth of a wheel; the axis of the latter is provided with an index for the purpose of measuring the entire number of revolutions of the mill. Among the more recent instruments the portable one of Lind (probably invented by Hales) deserves special attention, on account of the small surface presented to the wind, large surfaces always involving great

uncertainty. This consists of two parallel glass tubes about eight or nine inches long, half an inch in diameter, and connected beneath by a bent tube of one tenth of an inch bore. A metal cap, bent at right angles, is attached to the upper end of one tube, its opening receiving the wind. Both legs are so fastened to a vertical iron rod as that the wind keeps the whole instrument in the direction of its current. Water is poured into the tubes, filling them about half full. When the wind blows into the mouth of the metal cap, it depresses the water in one tube, causing it to rise in the other. The difference of level between the two tubes gives the height of a column of water whose weight is equal to the force of the wind acting on a surface of equal area. This anemometer gives approximately very accurate results. There are, however, three difficulties in the way of its general use: unequal temperature, evaporation, and the freezing of the water; on this latter account it were better to make use of dilute sulphuric acid.

According to the determinations of Rouse, the velocity of an almost insensible wind amounts to one and a half feet in a second; of one just perceptible, three to four and a half feet; of a pleasant wind, six to seven and a half; of a brisk wind, fourteen and a half to twenty-two; of a very brisk wind, twenty-nine and a half to thirty-six and a half; of a strong wind, forty-four to fifty-one and a half; of a very strong wind, fifty-eight and a half to sixty-six; of a storm, seventy-three and a half; of a violent storm, eighty-eight; of a hurricane, 117; and of the most violent hurricane, to 147 feet per second. Brandes estimated the velocity of a moderate wind at twelve to sixteen feet; Woltmann, that of a violent storm at seventy to eighty feet; Rochan, that of a tropical storm at 150 feet; the maximum being 600 feet. Kraft determined the velocity of the wind during a violent storm in St. Petersburg to be 110 to 123 feet. Finally, the wind appears to increase in velocity with the elevation.

Kaemtz has divided the winds into regular and irregular or variable. To the first class belong the land and sea breezes, the trade winds, and the monsoons. *Land* and *sea breezes* are experienced on coasts and islands, and are produced by causes already explained. After sunrise the land is heated to a greater degree than the sea; consequently, about ten A.M. a current sets in from the sea—a sea breeze—which reaches its maximum of intensity between two and three P.M., a calm again ensuing about sunset. Equilibrium of temperature between the two is soon disturbed by the greater depression of temperature on land produced by more rapid radiation; this being now cooler than the sea, a current of colder air pours out seawards from the land—the land breeze—which lasts until about eight A.M. In both cases an opposite current exists in the higher regions of the atmosphere. The land breeze is inconsiderable about peninsulas, but very sensible in bays. Similar periodical variations prevail also on the banks of great lakes, as also in long valleys and ravines.

It very frequently happens that currents of air, at different heights, move in entirely different directions, as shown by the motion of clouds of different degrees of elevation. This is illustrated by *pl.* 24, *fig.* 12, where *ab* is the direction of the lower, *dc* that of the upper current. In investigations into

these currents, small balloons, like those used so successfully by Thomas Forster, are very useful; in most cases four to five, and sometimes even seven to eight simultaneous different currents may be found to exist. According to the observations of Placidus Heinrich, instituted at Regensburg (Ratisbon) in the months of May, June, and July, 1791, the

North	wind	blew	9	times	above,	11	times	below
N.E.	"	"	11	"	"	12	"	"
E.	"	"	7	"	"	10	"	"
S.E.	"	"	3	"	"	9	"	"
S.	"	"	5	"	"	5	"	"
S.W.	"	"	15	"	"	14	"	"
W.	"	"	76	"	"	40	"	"
N.W.	"	"	19	"	"	44	"	"

The *trade wind*, which in the torrid zone blows constantly from east to west, may be readily understood from what has already been stated. In the vicinity of the equator, the air being greatly heated, expands and flows above towards the poles, at the same time that a counter current of cold air sets in from the poles to the equator. Had the earth no rotation on an axis, there would be a north wind on the northern hemisphere, and a south on the southern. But the earth turns on her axis from west to east once in twenty-four hours, and individual regions have an actual velocity which is greater with the vicinity to the equator. The air coming from the poles, and preserving its original velocity, must move slower towards the east than the earth itself, and consequently will have, in respect to the latter, a relative motion from east to west. This motion, combined with the motion from the poles to the equator, gives as its resultant a north-east wind to countries north of the equator, and a south-east wind to those south of it. These winds blow over the whole earth, but are generally only sensible at sea, at some distance (about fifty miles) from the main land. In the Atlantic the trade wind extends from 8° to 28° or 30°; in the Pacific to 25° N.L.; the limits in the southern hemisphere are less accurately determined. Sailors make use of these winds in the voyage from Europe to America, by steering south from Madeira nearly to the tropic of Cancer, whence, with little effort of the crew, they are carried west. In like manner the Spanish vessels went regularly from Acapulco to Manilla with this wind. Kaemtz assumes the limits of the north-east trade wind at 2° and 23° N. (the latter moves in summer a little more northerly, and in winter a little more southerly), that of the south-east trade at 2° to 4° and 21° S., the northern limit of the latter lying in the Atlantic Ocean in the northern hemisphere. In the vicinity of the equator the two trades become more easterly, and are separated by a zone in which there is generally an almost total absence of wind, hence called the region of *calms*. This has a mean breadth of about 6° (in August of $9\frac{3}{4}$°, and in December only of $2\frac{1}{4}$°), and lies somewhat north of the equator, from which its northern limit is a little further removed in summer than in winter. Nevertheless, the calms alternate incessantly with sudden squalls or storms and irregular winds. In the Indian Ocean the regularity of the trade wind is disturbed by the

shape of the surrounding bodies of land; only in its southern portions between New Holland and Madagascar, between 12° and 28° S. L., a south-east trade wind prevails the whole year. In its northern part south-west and north-east winds (monsoons) alternate; of these the former blow from April to October, the latter in the remaining half of the year. The cause of this phenomenon is to be found in the unequal heating of the neighboring regions inclosing this sea, and possessing opposite seasons at the same time. In the summer half year, when the sun is north of the celestial equator, the north or north-east countries, Arabia, Persia, and India, are the warmer, and the wind therefore blows over the sea to the land from the south-west; in the other half of the year, the sun standing south of the equator, the country to the south-west (Africa) becomes warmer, thereby producing north-east winds.

The upper current from the equator to the poles has, in the northern hemisphere, a south-westerly, in the southern, a north-westerly direction. The altitude at which this current commences has not yet been determined; on Teneriffe it prevails at an elevation of 9000 feet, while Humboldt found the easterly trade wind on South America at an altitude of 8000 feet. In all cases, the equatorial current becoming cooler, sinks deeper and deeper, finally reaching the surface of the earth. Thus in the higher latitudes the two opposite currents meet, and mutually interfere without any regular alternation taking place between them. On the great seas the west winds are tolerably regular between 30° and 40°, more so in the southern than in the northern hemisphere, and are used in the voyage to the Cape of Good Hope. In northern and western Europe the south-west winds decidedly predominate. The same is the case on the Atlantic, between Europe and North America, for which reason the voyage from Europe to America generally lasts longer than that from America to Europe. According to the recent calculations of Mahlmann at the mean latitude of the temperate zone, in both continents, a west-south-west wind is to be considered as the prevailing one See the chart of the winds (*pl.* 47. *fig.* 1) illustrating what has just been said.

The following table gives the number of times, that is, the number of days in the 1000, during which, on an average, each one of the eight principal winds blows in the countries mentioned in the table:

Countries.	N.	N. E.	E.	S. E.	S.	S. W.	W.	N. W.
England . . .	82	111	99	81	111	225	171	120
France	126	140	84	76	117	192	155	110
Germany . .	84	98	119	87	97	185	198	131
Denmark . .	65	98	100	129	92	198	161	156
Sweden . . .	102	104	80	110	128	210	159	106
Russia	99	191	81	130	98	143	166	192
N. America .	96	116	49	108	123	197	101	210

The season of the year has a great influence upon the direction of the

wind. In Europe the direction is more southerly during winter than in the other seasons; in spring (March and April) east winds occur, in summer (particularly in July) west and also north winds, and in autumn (especially in October) south winds. The strength of the wind depends partly on the season, being greatest in winter (January and February), and partly on the time of day, increasing in the morning towards noon, and then decreasing towards evening.

In Europe the wind when changing appears to move for any one place from north by east, south and west, as seems to have been first suggested by Lord Bacon, and after him by Mariotte, Sturm, Lampadius, Schübler, and others. The same relation seems to exist in North America. Dove first attempted to investigate this succession, and attained to the following results: In that part of the northern hemisphere where equatorial and polar currents alternate, the wind, as a general rule, shifts from the south by west, north, and east, and returns between south and west, as also between north and east, more frequently than in other directions. In the southern hemisphere the wind changes from south by east, north, and west, coming back more frequently between north and west, south and east. In the temperate, and probably in the frigid zones, where equatorial and polar currents constantly alternate, the wind at a mean appears to go round the quarters of the horizon in a definite direction, this direction being opposite in the two hemispheres. In the torrid zone, where polar currents alone prevail at the surface of the earth, there is no complete rotation of the wind. Nevertheless, whenever in the torrid zone, owing to the particular distribution of land and sea, a northern current alternates once a year with a southern, there will be but one complete rotation in the course of the year, and that in the direction which predominates in the south temperate zone.

The direction of the wind, as already remarked, exerts a decided influence on the height of the barometer. This, in western and central Europe, is highest during northern and eastern, lowest during southern and western winds. The following table contains the height of the barometer corresponding to the various winds, from observations made in the places mentioned:

	London. Millimetres.	Paris. Millimetres.	Berlin. Millimetres.	Carlsruh. Paris lines.	Dantzig. Paris lines.	St. Petersburg. Eng. inches.	Moscow. Millimetres.
N. . .	759.2	759.1	758.7	334.7	338.7	28.06	743.1
N.E. .	760.7	759.5	759.4	335.0	338.6	28.15	745.1
E. . .	758.9	757.2	758.8	334.5	338.8	28.15	743.9
S.E. .	756.8	754.0	754.7	333.5	338.8	28.16	741.7
S. . . .	754.4	753.1	751.3	332.8	337 7	28.07	740.6
S.W. .	755.2	753.5	752.6	333.4	336.3	28.07	740.3
W. . .	757.3	755.6	756.0	333.7	337.1	28.05	741.1
N.W. .	758.0	757.8	756.6	334.3	337.9	28.00	741.5

Curves have been constructed for different places, showing the dependence

of the barometer on the winds, as shown in *pl.* 28, *figs.* 4^a and 4^b. Now as the height of the barometer is in a certain connexion with the temperature, the latter must stand in a certain relation to the direction of the wind. In Europe, the temperature of the air is generally lower during northern than southern winds, and lowest of all during north-east winds; this rule, however, exhibits many occasional exceptions in different places and seasons. Thus, in Paris, during summer, it is coldest during south-west, west, and north-west winds, and warmest during south-east winds; in winter, on the other hand, it is coldest during north, north-east, and north winds, and warmest during south, south-west, and west winds. Curves exhibiting the connexion between the condition of the thermometer and the directions of the wind for a given place, are called by Dove thermometric wind rosettes (*figs.* 5^a and 5^b).

Unusually high winds or *storms* are caused by some great disturbance of the equilibrium of the atmosphere, which, in many cases, is produced by a rapid condensation of watery vapor, and the consequent rarefaction of the air; the air then rushes violently from all directions to the place of rarefaction, the place itself changing its position. This theory is maintained by Brandes and Espy. According to Redfield and Dove, storms are to be considered as whirlwinds, having a north-eastward progressive motion from the south to the north of the tropic of Cancer, the air in the whirl rotating simultaneously in a given direction. In the northern hemisphere this is from south to north by east. In *pl.* 23, *fig.* 63, AB represents the line along which the minimum of atmospheric pressure progresses. The circles described about A and B represent the whirl at the beginning and at the end of the storm. At the commencement of the storm, south-east or south winds will prevail at places south-east of AB; south-east at D and E; south at C and F; at the end of the storm the wind will have a westerly direction at these places. To the north-west of AB the wind will blow in the opposite direction. In the southern hemisphere the whirlwinds move from the north-west, and have the opposite direction of rotation.

Coasts and islands are especially subject to violent storms, owing to the absence of the mountains and elevated ranges which so eminently alleviate the force of the wind on the main land. On the coast of the North sea, the storms occur principally in November, and are preceded by calms and by an uncommonly damp warm atmosphere. Violent storms also occur on the coast of Norway, coming principally from the north-west, also ushered in by uncommonly warm weather. On the coast of Finmark, thirty-three storms were counted in the single year 1798; only twenty-six occurred, however, at another time during a period of twelve years. In the north frigid zone storms from the south-west and south are not rare; the most violent come from the south, shifting round to the north. Among the fiercest storms are found those which the mistral (north-east wind) produces quite frequently on land, on the Mediterranean, and even as far south as Africa. One of these, occurring on the 13th of October, 1782, pressed against an opposing surface with a force of 12lbs. to the square foot.

The most terrible storms of all, called *tornados, trovados,* or *hurricanes,*

occur in the torrid zone, particularly in the West Indies, where they produce at times appalling devastation. They take place nearly every year, beginning generally in the tropical regions, passing, however, out of these, and generally sparing the islands of Trinidad and Tobago, which are protected by high mountains; this, however, is not always the case, as has been generally believed. A peculiarity attending them is that the wind, during the continuance of the storm, changes its direction, generally blowing from all parts of the compass in succession; quite frequently, also, during the storm there occurs a lull, followed by a change of the wind to the opposite direction. Among the most devastating hurricanes of this century belongs that of 1809 in the channel of Mozambique, and on the island of Bourbon, Mauritius, and Rodrigues, as also that of August, 1837, which devastated the coasts of the main land of North America and the Lesser Antilles. *Pl.* 47, *figs.* 9 and 10, represent their sphere of influence. The explanation of these figures will be found in another part of the work.

Still more severe was the tornado of October 10th, 1780, which destroyed the fleet of Lord Rodney and a great number of merchantmen, killed 9,000 men in Martinique and 6,000 in St. Lucia, and levelled to the ground the towns of St. Pierre in Martinique, and Kingston in St. Vincent (fourteen only out of six hundred houses being left standing in the latter place). There was also a storm at Guadaloupe, in July 25, 1825, in which the wind appeared to be luminous; and the one of August, 1831, which, beginning on the 16th at Barbadoes, extended within six days over the islands of St. Vincent, St. Lucia, Granada, Martinique, Porto Rico, Cuba, and as far as New Orleans, destroying at Barbadoes alone ten millions of dollars' worth of property, besides the lives of 2500 men. Many tornadoes extend into the United States, particularly the southern portion of it, generally, however, losing a great part of their violence. Furthermore, the rainy season in the torrid zone, in Africa particularly, is connected with storms which often pass into veritable hurricanes. On the west coast of Africa, especially on the coast of Sierra Leone, two or three tornadoes form the transition from the wet to the dry season; these are most severe when unaccompanied by rain, and are then called white tornadoes. Very violent storms also rage on the east coast of South Africa, to which the Mauritius is exposed; the most devastating were in the years 1760, 1761, 1766, 1772, 1773, 1786, 1789, 1818 (when forty ships were torn loose from their anchors and mostly shattered to pieces, and many men on the island were destroyed), and 1824. The Cape of Good Hope is a dangerous neighborhood, on account of its storms, the most fearful of which are those which strike Cape Town. The storms on New Holland are also very severe, and during their continuance the wind blows from all quarters of the horizon.

The whirlwinds occurring in the seas of China and Japan, and devastating these coasts, are called *typhoons*. Resembling the hurricanes of the west Indies in their rotary motion, and the calm succeeded by the opposite wind, they differ in having a less conspicuous rectilineal progression.

The hot winds form a peculiar class, embracing the samum, the harmattan, the chamsin, the sirocco, and the solano. The three first appear to be

identical; *samum*, also simum, semum, simoom, or samiel (poisonous wind), is the name of this wind in Arabia, Persia, and in most countries of the east. It is called chamsin in Egypt, and harmattan in the negro tongue. The term chamsin, meaning fifty, comes from its blowing generally for the fifty days from April 27 to June 18, although sometimes the vernal equinox occurs in the middle of its period. These winds show themselves in greatest violence in treeless, sandy deserts, their distinguishing character being heat and dryness. A darkening of the horizon is the surest precursor of the simoom; when it actually arrives, the clear heaven vanishes, the sun loses his lustre, the air is filled with particles of sand, and all nature exhibits signs of the greatest disquiet. The heat becomes much more oppressive during the storm, particularly when columns of sand are carried along by the current. That the wind in itself is deadly, or at least injurious to the health, seems to be unfounded; at any rate the narrations of many of the earlier travellers appear to have been highly overcharged. Even the assertion that men and camels cast themselves on the ground at the approach of the storm, burying their faces in the sand, and thus await the passage of the blast over them, appears to belong to the class of fables; so much is true that the Arabians, during these storms, not unfrequently veil their faces and kneel down behind their camels. In western Asia, particularly in Arabia Petræa, and the deserts between Bagdad, Bassora, Aleppo, and Mecca, the simoom blows only during the months of June, July, and August, being most violent in July; it presents itself only by day, and on land, lasting at most only a few hours. With regard to the direction of these winds, they come on the borders of the desert from the following quarters: in lower Egypt from the south-west, in Mecca from the east, in Surat from the north, in Bassora from the north-west, in Bagdad from the west, in Syria from the south-east, &c. On the western coast of Africa, particularly in Senegambia, the wind is called harmattan; it there is injurious only to vegetation, being directly conducive to health by driving away fevers and other diseases. The chamsin in Egypt generally lasts from two to three days.

The *sirocco* of Italy, and the *solano* of southern Spain, are probably only continuations of the harmattan blowing in Africa, which loses its dryness in passing over Mount Atlas and the Mediterranean sea, retaining, however, its heat and relaxing properties. The influence of the sirocco, principally exerted in Sicily and Naples, and the isle of Malta, sometimes extends to southern Germany (the Tyrol and Steyermark). On the island of Madeira it blows as an east-south-east wind; it is there remarkably dry, accompanied by cloudless skies, and lasting about three days. The solano in Spain is likewise remarkable for its heat.

The *Föhn* which comes down from the Alps into some of the valleys of Switzerland is also supposed to be a continuation of the sirocco. It is a south wind, exceeding all other winds of the country in violence, before whose occurrence the sun becomes dimmed, and a haze forms over the sky. Shortly before the beginning of the föhn a north wind called *föhn-bise* generally blows in the higher regions. When the föhn approaches, plants wither, animals become restless, and the inhabitants experience a sensation

of weakness and relaxation. In spring it furthers the progress of vegetation in a remarkable degree, and causes the snow to melt very rapidly. It is most violent on the Lake of the Four Cantons, where it sometimes tears up nets lying deep in the water. It lasts generally but for a few hours, occasionally, however, for eight or more days; it blows with greatest intensity in spring and autumn, rarely in winter, and very seldom in summer. This wind was very remarkable in its appearance on the 18th of July, 1841, when it extended at the same time over a great part of Germany, even reaching as far as the Black Forest and the Odenwald.

The *Mistral* of South France cannot be considered as a wind allied to the sirocco and föhn; it is rather a very violent north-west wind, generally dry and cold, extending as a north wind as far as Algiers.

The *hot winds* in the south-eastern part of New Holland are very remarkable; these come from the high mountains in the north and north-east, and hardly yield to the hottest winds of Africa in their temperature.

Cold winds are less conspicuous and frequent than warm. They are felt in long valleys, and come from northern side valleys, and are especially cold when these contain ice and snow the year round. Winds of this character are principally found in Thibet, and are called *Burana* when they are stormy. In the deserts of Beloochistan they are accompanied during the summer months by copious falls of rain. The cold storms of the Russian Steppes, called *Wiuga*, are exceedingly devastating, being accompanied by snow squalls, and lasting generally three days.

Whirlwinds arise from the meeting of two winds blowing from opposite directions; these sometimes, even on calm days, set sand, dust, &c., into a whirling motion, frequently lifting these objects to a considerable height. Very violent whirlwinds produce the so-called *trombs* or *weather columns*, also called *wind* or *water* spouts, as they occur on land or over the water. The name tromb (French) is borrowed from the trumpet-shape of the object. In every phenomenon of this nature there is a kind of cloud which descends in a hollow column from the clouds above to the earth, or to the surface of water. This progresses with varying velocity, rotating on a vertical axis, and taking up water as well as dry substances, which it sometimes elevates to the height of several hundred feet. These spouts generally form a hollow, straight, or curved double cone, whose upper part, with the point downwards, proceeds from a cloud; the lower part, with the point directed upwards, consisting of water, sand, and other substances. The color is generally grey, dark blue, dark brown, and sometimes fiery red; the middle portion is frequently transparent. The force exercised by these spouts is, in many cases, truly enormous; they uproot trees, unroof houses, hurl men and other objects to a great distance, &c. The motion of the spout is often very rapid and tempestuous, some traversing seven or eight miles in an hour, while others can readily be followed on foot; they rarely, however, stand still. Horner asserts the following propositions with regard to water-spouts proper. They arise for the most part only in the vicinity of land where inconstant winds blow and the temperature is very

variable, and are always accompanied by thunder and lightning, or electrical phenomena. Around them calms generally prevail. They carry along with them all objects taken up. They arise sometimes from the clouds, sometimes from the water; their mass consists of watery vapor, and not of solid water; their greatest diameter varies from 2 to 200, their greatest height from 30 to 3000 feet. A figure of a water-spout is seen in *pl.* 27, *fig.* 1. *Land whirls*, according to Horner, have the same origin with water-spouts; they are, however, more impetuous and destructive, not being retarded or impeded by the weight of water. Peltier has found recorded 116 whirls, of which sixty belonged to the land, and fifty-six to the sea. Of the former the oldest was in 1456, of the latter in 1664. Of the entire number twenty-nine (eighteen by land and nineteen by sea) exhibited a circular motion, and twenty-two (thirteen by land and nine by sea) no internal motion at all; forty-one (twenty-five by land and sixteen by sea) were accompanied by thunder and lightning; ten carried the objects taken up in a direction opposite to the wind; sixteen ended with hail; six vanished in a cloudless atmosphere without doing any damage. Of the water-spouts, three shook fresh water over the ship, although on the sea; in fifteen the water was seen to rise; in eight to sink down; two connected an upper cloud with a lower; in eight cases a sulphureous smell was perceived; in six cases several spouts were seen at the same time; thirty-four exhibited peculiar phenomena.

5. *Of the Moisture of the Atmosphere.*

A greater or less quantity of water is always dissolved in the air in the form of vapor. This vapor, under ordinary circumstances, is invisible, but becomes visible when it returns to its liquid state in the form of dew or frost, fog or cloud, rain or snow. Certain instruments, called *hygrometers*, are employed to determine the amount of watery vapor contained in the air. The hygrometers formerly employed had for their basis some organic or inorganic body, which became elongated or increased in weight by absorbing watery vapor, the amount of absorption being in proportion to the amount of vapor in the atmosphere. The best instrument of this kind was the *hair hygrometer* of Saussure. A soft pale human hair is boiled for half an hour in a solution of sulphate of soda, and then for a few minutes in pure water, washed off in cold water, and dried in the shade. It is then fastened by its upper extremity to a little tongue, the other end being wound round a minute pulley provided with two grooves. Round the other groove passes a silk thread, from which is suspended a weight of several grains to keep the hair in a state of constant tension. An index, fastened to the pulley, traverses a graduated arc whenever the pulley is turned in either direction by the contraction or expansion of the hair. To graduate the instrument and fit it for its proper office, it is first introduced into a receiver, in the bottom of which has been placed heated chloride of calcium or concentrated sulphuric acid, and after the air has been exhausted, the place noted where

the index stands; this will be the point of greatest dryness, or the 0 of the scale. It is next placed in a receiver provided with a basin of distilled water, and the new position of the index marked: this will indicate the maximum of moisture, or the 100th degree of the scale. The interval between the two extremes is then to be divided into one hundred equal parts. Other substances employed in hygrometers are from the animal kingdom: 1. Catgut, as used in the Dutch hygrometers, consisting of a paper house in which is suspended a piece of gut. The lower end of the gut carries a disk of paper, on which are fixed two figures, one a man with an umbrella, the other a woman with a fan; the former comes to the door when the moisture causes the string to turn, and the latter when this is untwisted by the dry air. 2. Quills, as proposed by Chiminello. 3. The skin of the frog, fish bladders, gold beaters' skin, silk, ivory (employed by Delue, who afterwards substituted whalebone), &c., &c. The vegetable kingdom has furnished hempen threads, thin boards of pine or mahogany, or box wood, paper (especially straw paper), grasses, awns of oats, and a species of erodium. From the mineral kingdom have been derived solutions of sal-ammoniac, in which a sponge is dipped, salt, sulphuric acid, &c., &c. All these, however, are inapplicable to the purposes of science, owing to their great variability and the readiness with which they lose their hygrometric properties.

The *hygrometer of Daniell* is constructed on an entirely different principle from the preceding, namely, condensation and rarefaction. This consists of a curved exhausted glass tube, ending in two bulbs, the one having a thin coating of gold or platinum foil, the other covered with a fine linen rag. The first bulb is half filled with sulphuric ether, and contains a small thermometer, the graduated portion of which passes up into the tube. On dropping ether on the other bulb, its rapid evaporation produces a considerable degree of cold; the vapor of ether in the tube becomes condensed, thereby permitting a new evolution from the ether in the bulb. The formation of vapor in this bulb cools it by rendering some of its heat latent, thus causing it to become covered with a delicate dew. The dew point can be read off on the inclosed thermometer, that is, the temperature at which condensation or the deposit of vapor begins, this taking place when the air is saturated with moisture. The reason that the dew point can serve to determine the amount of watery vapor in the atmosphere is found in the following considerations: The air is said to be saturated with moisture when the vapor contained in it has attained the maximum of tension and density, corresponding to the existing temperature, which is not always the case, for the warmer the air, the greater may be the tension and density of the vapor contained in it. When moist air is cooled, it is incapable of containing as much vapor as before; a portion then becomes condensed in the form of minute vesicles. This condensation will take place sooner with a given reduction of temperature, the more vapor is contained in the air, or the nearer it is to the maximum of condensation corresponding to the existing temperature. Upon the same principle depends a more perfect instrument, invented by Dobereiner, and recently improved by Regnault.

All hygrometers depending on the principle just mentioned, are subject to

the defect of causing a great expense of ether, and of not allowing any condensation at all when the weather is very dry. *August's psychrometer* is far preferable, and in all probability will soon supersede other hygrometric apparatus. The principle is the same as that proposed by Hutton, and employed by Leslie in his differential thermometer. The psychrometer consists of two very sensitive thermometers, attached or freely suspended to the same frame; of the two bulbs, one is wrapped with a linen rag, the other is free. On moistening the first bulb, without leaving any water dripping, an evaporation takes place, which is rapid in proportion as the air is removed from the point of saturation. This evaporation reduces the temperature of the inclosed bulb, and the mercury sinks in proportion as the air is removed from the point of saturation. Thus from the difference of temperature in the two thermometers we can draw a conclusion as to the condition of moisture in the atmosphere. The psychrometer thus does not give the dew point itself, but the point of greatest density, that is, the temperature at which the external air is so saturated with vapor, as to be incapable of taking up an additional amount without condensation occurring with a further reduction. By the use of certain formulæ we can avail ourselves of the indications of the psychrometer in determining the dew point itself.

The amount of moisture in the air varies through the day. According to the researches of Kaemtz and others, it twice reaches a maximum and twice a minimum; the former occurs about 9 A.M. and 9 P.M.; the latter shortly before sunset, and about 4 A.M. Nevertheless, in a certain sense we may say that the air is most damp about sunrise, as it is then coldest, and nearer the point of saturation or the dew point than at any other time of day. We do not then mean that the air contains absolutely the most moisture at this time, but most in proportion to the temperature. In summer the minimum of moisture is at about 3 P.M. On high mountains the changes in the condition of moisture in the air follow another law, the ascending currents carrying the vapor upwards. This condition also varies with the month and season. From observations instituted in London, Paris, Geneva, and the great St. Bernard, the absolute amount of vapor at those places was least in January, and greatest in the end of July or beginning of August; on the other hand, the relative moisture was greatest at the three first named places in December, and least in May (beginning of May at Geneva, end of May at London and Paris). The summer months are then, with respect to the relative moisture, the dryest, and the winter months the dampest. The elasticity of the vapor is likewise different at different seasons for the same place, being subject to many variations, and particularly to the influence of the wind. Dove has shown from Daniell's observations, that the pressure of the vapor atmosphere is much less during north and south winds than during eastern and western; Kaemtz ascertained, likewise, from observations made at Paris in 1827, that on an average the minimum of pressure lay in north-east winds, the maximum in those a little west of south; in summer, however, considerably east of south. The relative amount of moisture in the air also varies with different

winds; on an average the air is further removed from the condition of saturation during north-east winds, than during southern and south-west winds, although occasionally decided exceptions to these general principles occur.

As the formation of vapor depends partly upon the temperature and partly upon the presence of water, it follows that the dryness of the air must increase with the distance from the equator and from the sea, an inference well established by observation.

A partial condensation of the vapor of the air takes place whenever it is brought into contact with a sufficiently cold body, whose temperature is lower than that which corresponds to the density of the existing vapor. A part of the latter is thus deposited on the cold body in the form of minute vesicles. The moister the air the less the temperature of the body needs to differ from that of the air. In this way we explain the coatings of moisture on the window panes of an inhabited room, whose temperature is higher than that of the external air, so that the panes are coated from within, a phenomenon which is only exceptionally reversed, and this especially in spring. *Pl.* 23, *fig.* 55, shows the symmetrical manner in which these vesicles are deposited.

Of Dew.

The local deposit of moisture referred to well illustrates the theory of *dew* in general. When after sunset the sky is clear and the air calm, a great radiation of heat takes place from the earth, accompanied of course by a diminution of temperature. The layers of air in contact with the earth and objects upon it become cooled, and when this reduction of temperature reaches the dew point, a deposit of vapor ensues.

To determine the amount of dew we make use of a *drosometer*, an instrument still very imperfect and inadequate. By drosometer is to be understood a balance, the shorter arm of which carries a plate, readily bedewed, the other arm a counter weight. Instead of the plate, as used by Wilson and Flaugergues, we may use to advantage a bunch of wool or eider-down, to be appended to the shorter arm. Wells, to whom we are indebted for the first rational theory of dew, used flocks of wool weighing ten grains, pulling them into a mass of about two inches diameter, and measuring their increase in weight after exposure. Lambert proposed to expose well washed and curly hair to the air, and then to ascertain its increase of weight in a given time.

The following generalities respecting dew are furnished by Wells. Dew is formed in greater quantity during clear calm nights, especially when clear and calm weather succeeds to stormy. Clouds prevent the formation of dew, as also brisk winds, which constantly replace the cooled air by warmer. Little dew falls during a night when the sky is cloudy and the wind still; none at all when a cloudy sky and windy weather are conjoined. Objects interposed between the radiating surface and the clear sky, produce the same effect as

clouds; consequently, bodies standing freely exposed to the heavens, exhibit the greatest deposit of dew. Even a piece of paper, or a fine pocket handkerchief, will prevent the deposit of dew. A bundle of wool lying underneath a piece of paper gained only two grains of dew, while another of equal size, but exposed freely to the sky, gained sixteen grains, or eight times as much. *Fig.* 36, *pl.* 23, presents an apparent exception to the law. Lay a metal plate, AB, on high grass, heavy enough to press down the grass and thereby to become surrounded by it, and at the same time support a similar plate, CD, on thin props above the average height of the grass, thus exposing the plate to the open sky. The first metal plate will in many cases be bedewed, while the second is found to be entirely free from moisture. This result is unquestionably produced by the cooling influence of the grass on the former plate. The action of an oblique exposure to the sky is shown by another experiment (*pl.* 23, *fig.* 37). Under the elevated board, FG, lay a small quantity of wool at C, ten grains for instance; on account of the board this cannot radiate heat towards the part AB of the sky, it will therefore be less bedewed than if it had been freely exposed. Around the stem and under the branches of a tree less dew falls than in the surrounding free exposure. In the case represented by *fig.* 38, little dew will be deposited in the space represented by AB, determined by verticals tangent to the outer circumference of the branches. Differently inclined surfaces experience different deposits of dew. Let *fig.* 39 be a vertical section of a certain region of considerable unevenness, while apart from this the radiating power is everywhere the same; then more dew will be deposited on the horizontal portion, AB, than on the slope, BC; more also than on CD. The least deposit will be at E. If a body be placed at H, on the same level with AB, it will be less covered with dew, on account of the intercepting action of the walls F and G, than if it lay on AB. Two observers would obtain very different results, one of whom should be stationed on a well wooded and inclosed slope, like the foreground of *fig.* 40, and the other on the open height in the back-ground of the same picture.

An instructive experiment is performed by suspending a glass ball at some height above the ground. In a perfectly calm clear night the first moisture will be exhibited on the very summit of the ball; by degrees the dew drops will extend over a great portion of the ball, constantly diminishing in size, as in *pl.* 23, *fig.* 41. A similar action is observed on a bent sheet of paper, a dead insect (*fig.* 42), and on the back of a sheep lying quietly on the earth (*fig.* 43); in the latter figure the greatest horizontal section, ABC, indicates the boundary between the more and the less bedewed portion.

Since different bodies possess very different radiating properties, and consequently cool in a very unequal degree, it follows that under precisely the same circumstances the deposit of dew on these different bodies would be very different. Thus on plants it is more copious than on the earth; on grass and leaves more than on bushes and trees; on loose gravelly land more than on the hard-trodden soil; on glass more than on metals, &c

Plane and horizontal pieces of glass are well adapted for observing the formation of dew. *Pl.* 23, *figs.* 44–47, show how the drops, small at first, afterwards increase and run together. Wool deserves the preference so far, that besides readily receiving the dew, it retains it for some time. The amount of dew produced depends not so much on the quantity of wool as upon the manner of its arrangement. A certain quantity of wool rolled up in a ball (*fig.* 48) will receive much less dew than if spread out flat. Metals become dewed very slowly, although there is a difference in this respect, platinum, iron, steel, and zinc, receiving a greater amount than gold, silver, copper, and tin. Metals purposely moistened sometimes become dry while other bodies are becoming coated. If a metal be combined with a substance of some thickness, capable of being strongly bedewed, the radiating power of the metal is not increased, as might be supposed, but diminished, and the resistance to the deposition of dew presented by the metal may even be communicated to other bodies lying upon it. Thus wool on a plate of metal becomes less wetted than if lying on a plate of glass. If, however, a piece of gilt paper be laid with its unmetallic side upon wood, the paper will be perfectly dry where it is in contact with the wood, and the metallic side will become bedewed (*figs.* 49–52).

If a watch-glass be laid on a plate of polished tin, with the concave side up (*pl.* 23, *figs.* 53^a and 53^b), a dry zone will be seen on the outer border of the glass, and a circular dry space in the centre, the two separated by a zone of dew, exhibiting the largest drop in the middle. An example of the regularity with which dew is deposited around a row of wafers laid on glass, themselves receiving no dew, is seen in *fig.* 54. Finally, *figs.* 56 and 57 show the dewing of spiders' webs.

According to the experiments of Wells, it is not correct to assign morning and evening as the time of greatest deposit of dew. It seems rather to be deposited during all hours of the night, more abundantly, perhaps, after midnight than before it. In shaded places it appears to form even in the afternoon. Nevertheless dew is not deposited in all countries in equal quantities. It is most copious in the coast regions of warm lands; for instance, along the Red Sea, the Persian Gulf, the coast of Coromandel, at Alexandria, and in Chili. On the other hand it is almost entirely wanting on the arid plains in the interior of continents, as in central Brazil, in the deserts of Sahara and Nubia, &c. It is very rarely seen at sea.

That dew does not ascend, as supposed by the earlier philosophers, is now not a matter of controversy. Other things being equal, the amount of dew will be in proportion to that of moisture in the atmosphere, for which reason heavy dews are frequently the precursors of rain. With equal quantities of moisture in the air the dews of cold nights are more copious than those of warm. Dew-water, when collected, is found to be almost chemically pure, containing, however, some carbonic acid. The sticky deposits found on plants, called honey-dew and meal-dew, do not proceed from the atmosphere, but consist of the secretions of Aphides and other insects.

Of Frost.

Frost is, in most cases, nothing more than dew which has been frozen in the form of minute crystals, after being deposited on the surface of bodies cooled below the freezing point. The formation of frost, then, follows the same laws as that of dew. Frost is distinguished from ice in not forming a smooth covering, but consisting of crystals of ice which hang sometimes loosely, sometimes fast, to the different objects, and resemble snow crystals in form. That frost is somewhat different in its origin which arises in winter, when, after a long period of cold, a warm wind follows, depositing watery vapor on all bodies without exception. This kind of frost also consists of ice crystals, with which projecting thin bodies, especially the stalks of plants, &c., are coated. It generally arises in clear nights, although sometimes when the sky is covered with clouds, and is especially frequent in polar regions, where the cordage of vessels is frequently covered with brilliantly white fringes. *Fig.* 59 exhibits a remarkable frost formation on the chiselled star of a tomb-stone. *Figs.* 60 and 61 represent the same on fallen leaves. *Pl.* 24, *fig.* 2, presents two trees trained along a wall, in which only those branches outside of the line, AB, are exposed to frost. To the second kind of frost belong the fine crystals which coat the thick walls of houses, when a returning warmth succeeds a period of continued great cold. An allied phenomenon, very interesting in its character, is exhibited in the formation of "ice flowers," or crystallizations of ice on the window panes of chambers. Some of these are shown in *pl.* 24, *figs.* 3–6. *Fig.* 1 presents a peculiar crystallization on the windows of a drug store, where the jars and bottles standing near the window were depicted on it in frost.

Of Fog.

Fog may be produced in two ways: first, by the cooling of air filled with moisture to the dew point, the condensation taking place in the air itself, and impairing its transparency; secondly, by the diffusion of vapor arising from seas, lakes, rivers, or moist ground, in a cold atmosphere already near the point of saturation. It consists of minute vesicles of water filled with air. Fogs are very frequently seen over the surface of water in winter during calm and cold weather; also early in the morning during spring and autumn. Of a similar character is the cloud which forms over the surface of meadow or other moist lands. In all these cases the temperature of the air at the surface is less than that of the water or soil, the air itself being nearly saturated. Water cools much more slowly than air, owing to sinking of the superficial strata when cooled, their place being supplied by warmer portions. If, then, considerable bodies of water be of nearly the same temperature as the air, it will happen that during clear nights their temperature will be higher than that of the surrounding land. The air over the land will thus be cooler than that over the water. If the two

(supposed to be near the point of saturation) be mixed, a precipitation of some of the water in the form of a fog will result. *Pl.* 24, *fig.* 7, is intended to illustrate the formation of fog at a certain place in England on a particular day. The temperature of the surface of the river was 56°, that of the air six feet above the water 47½°, that of the land on the bank of the river 45°, and that of the air above the bank 49° F. The greater heat of the water, compared with that of the incumbent air, caused the formation of fog over the river; as, however, the temperature of the river bank was less than that of the air over it, the outlines of the fog were confined to the surface of the river. *Fig.* 8 shows the overtopping of the trees by the fog. *Fig.* 9 is an example of the formation of fog over a river inclosed by hills.

Counting every day during which fogs are present for any length of time as a *foggy day*, we shall find that for one and the same place, the number of such days in different years is very nearly the same; not so, however, in different places. It has been observed that by far the greatest number of fogs experienced in London, Hamburg, Berlin, Stuttgard, and Munich, occurred in winter and autumn, while in Moscow foggy days are as numerous in summer as in winter.

Fogs are much rarer on level lands than in mountainous regions; on the dry plains of Asia and Africa they are almost entirely wanting. Next to mountains they are thickest on the shores of large bodies of water, and are more abundant as we approach the poles from the equator. They are especially prevalent in the Northern Atlantic in the neighborhood of Newfoundland, New Scotland, and Hudson's Bay, all noted for their fogs. The reason of their occurrence in these places is the condensation of the vapor arising from the Gulf Stream by the colder air. It often happens that fogs are very thick on the decks of vessels, while the tops look out on a clear sky. The coast of California is almost continually veiled in fogs; even on the coast of Peru they last from four to five months at a time. Fogs are also frequent on the coast of Norway and of England. Beautiful exhibitions of fog occur on the English coast, particularly on the hills inclosing the harbor of Plymouth (see *pl.* 24, *figs.* 13–18). Indicating the hill to the left by A, the promontory in the centre with the tower by B, and the wooded hill by C, then in *fig.* 13 we see a strong condensation of vapor over A, observed about 5 P.M., of July 22, and only a slight one over B. Half an hour later A presented the same appearance, but the fog had increased over B, and covered a part of C. About 6 P.M. the fog had increased over A and completely enveloped B; it had become shorter but higher over C. On the 2d of June, about 8½ A.M., the fog had the appearance presented in *fig.* 14, although the upper outline of the fog was not so regular as in our figure. About 4 P.M. the fog over A had entirely vanished, as in *fig.* 16, a dense cloud apparently rested on the hill, and seemed to hang over the water, together with the fog; B and C were, however, completely enveloped in fog. *Fig.* 15 represents a fog resting on the water against C, having a regular outline above, and concealing half the mountain.

Isolated masses of fog are often observed on mountains, having only a

few feet of diameter, and vanishing at a certain height of air. This generally occurs during rainy weather, and is usually a sign of its continuance.

The densest fogs occur over cities; and these, in addition to vesicles of water, appear composed of various exhalations. This, for example, applies to the dense fogs of London, Paris, and Amsterdam, which may therefore be called mixed fogs.

Besides the fog composed of vesicles of water, there is a dry fog, the principal compound of which is probably smoke or other exhalatory matter. Occasionally it occurs in great quantity, as in the years 1783 and 1847. Without diminishing the transparency of the air as much as is done by fogs, it dims the sun, and causes him to appear red and shorn of his beams. This phenomenon is most frequently observed in the Netherlands, in Northern France, and Germany; more rarely in England, and still more so in Southern and Eastern Europe. In the United States it is especially prevalent, particularly in autumn, about the time of what is called Indian summer. Natural philosophers are not agreed as to the cause and components of this dry fog or haze; according to some it is of electrical origin, according to others it consists of the smoke and exhalations of burning and decomposing substances, as also from volcanoes. The latter theory is probably the correct one. The occurrence of this fog in Germany unquestionably depends on the burning of turf or moors in Westphalia and East Friesland, especially in the moor regions of the coast of the North Sea, where from May to July the turf is dug up, dried, and burned for manure. The spontaneous burning over of extensive tracts of forest land would also contribute to a very great extent.

Of Clouds.

Cloud is nothing more than fog which has reached or been formed in the higher regions of the atmosphere. Although the water of which the cloud is formed is heavier than air, yet its disposal in the shape of hollow spheres diminishes very much its gravity; and even should it sink through the lighter strata of the air, it will ultimately come to a denser, warmer, and less saturated part of the atmosphere. Here the cloud will be dissolved at its lower face, while new fog will be condensed on it from above. Hence the nearer the atmosphere is to the point of saturation, the lower do the clouds sweep. Whenever the cloud gets into a current of air it is carried along with it.

The classification of clouds now almost universally adopted is that of Howard. He establishes three elementary and four secondary forms. The primary forms are: 1st. *cirrus* (*pl.* 25, *fig.* 1), consisting of light and feathery streaked filaments seen in clear weather; 2d. *cumulus* (*fig.* 2), composed of huge hemispherical masses, apparently resting on a horizontal base, occurring chiefly in summer, and presenting the appearance of heaps of snow; 3d. *stratus* (*fig.* 3), an extended horizontal layer of cloud,

increasing from below, and appearing at times about sunset, of extraordinary brilliancy. The secondary or compound clouds are—1st. *cirro-cumulus* (*fig.* 4), forming the transition from cirrus to cumulus, and constituting the aggregations of small round white clouds, resembling sheep in a meadow; 2d. *cirro-stratus* (*fig.* 5), consisting of cirrus combined in horizontal or slightly inclined layers of considerable extent; 3d. *cumulo-stratus* (*fig.* 6), often giving to the horizon a bluish-black color, frequently seen to great perfection towards night of dry and windy winter weather; 4th. *nimbus* (*fig.* 7), or rain cloud. *Fig.* 8 exhibits cirrus and cumulus in the upper part above the thunder cloud. It must be readily understood that the precise reference of a cloud to one or the other of these modifications just described, must be sometimes a matter of great difficulty.

The sheep-like cirro-cumulus, when verging closely on cirrus, generally precede clear mornings and evenings, and are mostly indicative of continued good weather. Many philosophers, Kaemtz among the number, suppose the cirrus cloud which soars far above the others, frequently at a height of 20,000 feet above the earth, to consist not of vapor, but of particles of snow or ice. The cumuli are most abundantly seen in the horizon, and are of dazzling whiteness on their borders, and dark in the middle. Their appearance is frequently not unlike a snow-capped mountain. The stratus is often nothing other than a layer of fog or mist, and occurs at all heights, frequently of great extent. Cirro-stratus occurs in various forms and colors, being generally seen in morning and evening, and giving rise to the beautiful redness of the sky. According to Howard, that haze covering an otherwise clear sky as with a veil, and most frequently the forerunner of bad weather, belongs to this class. The thick rain-threatening clouds arising from the combination and expansion of cumulus belong to the cumulo-stratus.

The position of cloud is generally horizontal, it being only rarely that single clouds depend vertically, as in the case of wind and water spouts. The thickness of the different clouds is very various and difficult of determination. Peytier and Hoffard ascertained the thickness of cloud strata in the Pyrenees to be 1400 and 2600 feet in two successive days. The greatest observed thickness amounts to 5000 feet, although cases must occur where this is vastly exceeded.

The height of the clouds is much better known, although there are considerable difficulties in the way of ascertaining this elevation. Various methods of different degrees of merit have been proposed by Riccioli (for two observers at a known distance apart), Wrede (making use of the shadows of clouds), Kaemtz, Arago, and others. More recently Wartmann has proposed the use of the artificial horizon. According to Riccioli, the maximum height of the clouds is 25,000 feet. According to the measurements of Lambert, the minimum height is 7300, the maximum from 15,000 to 20,000 feet. Gay Lussac, after ascending in his balloon to a height of 21,600 feet, saw small clouds still at a considerable distance above him. According to Kaemtz, cumulus sweeps along at a height of between 3000 and 10,000 feet; cirrus between 10,000 and 24,000 feet; thunder-cloud between 1500

and 5000 feet. Pouillet instituted very exact measurements in 1840, during which he found clouds at an elevation of from 22,300 to 38,000 feet. In general we may assume that the thin cirrus cloud does not descend below 2000 or 3000 feet of elevation, while the thicker rainy clouds may come within a few hundred feet of the earth, although they may occur at much greater elevations. Clouds appear, furthermore, to attain a greater height in low than in high latitudes, the watery vapor being carried higher in the former than in the latter.

It is very difficult to ascertain the distance of a cloud from us, its apparent place being of not the slightest use in the determination. When the distance of a cloud is unknown, it becomes impossible to find out its actual size; and even the very shape is sometimes a matter of ambiguity. A change in the position of the cloud causes a change in its external appearance. This is shown in *pl.* 24, *fig.* 11, where the observer at E sees the same cloud at one time lower under the angle AEC, at another time higher, and evidently very differently, under the angle BED. Thus the same cloud might appear quite dissimilar from two different stations at the same instant of time. To an observer at A (*fig.* 10) the sky will appear furnished with clouds which are quite invisible to the one at B, the view being intercepted by a uniform stratum.

Clouds of very different character are often brought into contact by aerial currents or changes in the density of the atmosphere. Thus in *pl.* 26, *fig.* 1, a cirrus and a cumulus cloud are apparently brought into contact; in *fig.* 2 a cirrus appears resting on the summit of a cumulus; in *fig.* 3 a cumulus appears to have its summit cut off by a horizontal layer of cloud. Such contacts of clouds are partly real, partly only apparent. The apparent occur when two clouds lie in the same line of sight from an observer, although they may actually be quite widely separated. Thus to the mountain observer at S (*pl.* 27, *fig.* 12) the two clouds, M and N, appear to be in contact, while to the one stationed on the plain at P, their relation to each other is very different. In *pl.* 26, *fig.* 4, also, it is only apparently that a range of cumulus appears embedded in a dense black layer of cloud. *Fig.* 5 shows two clouds actually in contact, but likewise apparently combined by a long thin streak of cloud. *Fig.* 6 presents an apparent mixture of cirrus with light transparent fog, relieved against a mackarel-back sky. *Fig.* 7 shows an apparent contact of cirro-stratus with cirro-cumulus.

Clouds under different illuminations present very different appearances. Sometimes a cloud appears entirely in shadow; at another time its upper or lower border seems illuminated (*pl.* 26, *figs.* 8 and 9), A and B. As the shadows of clouds depend upon their different positions with reference to the sun, it is very evident that the same cloud will appear very differently in the morning and in the evening, in the north and in the south. If we assume that one mass of cloud, AB (*fig.* 9), stands in the south, and another, A′B′, of similar shape in the north, then to an observer between them the northern cloud, A′B′, will present its illuminated face, exhibiting only a small portion of the shadow, while the other cloud will appear entirely in shade.

In *pl.* 27, *fig.* 2 exhibits the appearance presented when the sun stands behind a cloud. *Fig.* 3 is an example of the diverging shadow of a layer of cumulus combined with cirrus. *Fig.* 6 illustrates the fact that objects on the earth, and especially mountains, can cast shadows into space.

About sunset diverging shadows of great beauty are often seen among clouds in the west. If these shadows are long enough to pass the zenith, they will converge to a point in the eastern sky opposite to the sun; the opposite phenomenon takes place at sunrise. A beautiful illustration of this, represented in *fig.* 5, was observed by Faraday in the Isle of Wight. Ten to twelve streaks of light and shadow were visible in the north-east, south-east, and south, apparently proceeding in a straight line from a point of the horizon between south and east. The atmosphere contained a light fog presenting but slight impediment to the sun's rays. Clouds in the west prevented the transmission of light, and immense parallel shadows crossed the entire heavens, in an almost horizontal direction.

We must not omit to make particular mention of the beautiful coloring presented by the clouds, especially at time of sunrise and sunset, which we shall have further occasion to refer to in treating of the morning dawn. As the clouds principally absorb the blue rays, they generally transmit the red, although we may have successive changes to yellow, orange, carmine, and purplish red. The situation of the cloud has great influence on its colors. In the immediate vicinity of the sun these are most brilliant. When directly in front of the sun they appear sometimes darker (*pl.* 27, *fig.* 8), and sometimes lighter and colored (*fig.* 9). This position of clouds just before the sun, gives rise at times to very interesting phenomena. A remarkable case was observed by Howard, where irregular streaks existed on a dark cloud, the intervals filled by clouds of a less dense but homogeneous texture. When the sun came behind the bright part of the cloud, the latter appeared suddenly covered by an irregular and rapidly moving network (*fig.* 10), although the great mass of the cloud exhibited no motion. No motion was perceptible when the sun came in contact with the dark streaks. *Fig.* 11 shows the apparent contact of the lower edge of the sun's disk with an upper edge of a layer of cloud.

Of Rain.

Rain is produced when, by the continued condensation of watery vapor, the separate vesicles unite into drops which are too heavy to float in the air, and consequently fall, increasing in size with the descent. To determine the amount of rain falling in any one part of the earth, we make use of an instrument called a *rain gauge*, and also ombrometer, udometer, hyetometer, pluviometer, &c. One of these is represented in *pl.* 23, *fig.* 64. It consists of a prismatic or cylindrical tin vessel, B, of five to seven inches in diameter, on which rests a second cylinder, open above, and with a funnel-shaped bottom perforated in the centre. Rain water falling on A passes through the aperture into the vessel B; this, however, is connected by the

bent tube, C, with a glass tube, D, from which latter the height of the water in B can always be ascertained. If A and B have the same cross-section, the height of the water in B will express the depth to which the rain water would stand on the earth in a given time, provided that no evaporation and absorption took place. The rain gauge must be set in an open place, so that it may not receive water from any other source than the clouds. In temperate regions, however, the amount of rain which falls is sometimes only a few hundredths of an inch or line; we therefore advantageously use a graduated tube, whose cross-section is a known aliquot part of that of the rain gauge, and into which the water from the greater vessel flows or is poured. If, for example, the diameter of the tube is one third that of the rain gauge proper, the water will stand nine times higher in the former than in the latter, which gives us a much better opportunity of ascertaining the value of small amounts. Conical gauges are also employed, yielding excellent results in slight rains. Self-registering rain gauges have been constructed quite recently, some of considerable excellence.

Pl. 29, *fig.* 1, is intended to illustrate the different conditions with respect to rain presented by different portions of the earth. The annual fall generally diminishes as we recede from the sea, and increases with the height of the place above the sea; at one and the same place, however, the amount of rain decreases with the height above the ground. Thus Dalton observed that the amount of rain on the top of a high tower compared with that at the bottom was as 2 : 3 in summer, and as 1 : 2 in winter. From nine years' observation at the observatory of Paris, it was found that the amount of rain on one terrace was about 0.116 less than on another twenty-seven metres below. The reason of this difference is, that fresh vapor is constantly being condensed on the drop in its descent, and consequently the drops must be largest just before reaching the ground. The nearer to the point of saturation the air happens to be, the more considerable is the difference just referred to; for this reason it is less at Paris in summer than in winter. If it be very great, long continued rainy weather is to be expected. This difference is not the same in all countries, and is less at Paris than in England. In warm countries, and in the warmer portion of the year, the rain is generally heavier than in cold countries and in the colder months. Between the tropics the rain sometimes falls to the depth of an inch in an hour, and Humboldt, in single instances in South America, observed from four to five inches in the same time. It is only very rarely that rain, to the amount of an inch in an hour, falls in higher latitudes.

On the continents of the torrid zone a rainy season of many months' duration sets in about the time of greatest heat, the heavens being clear during the rest of the year. When the sun is in the zenith the rain is most violent and copious. The duration of the rainy season is generally three to five months. Near the equator, where the sun stands twice in the zenith, and, indeed, on days which are separated by several months, there are two wet seasons, either separated by a dry one, or exhibiting a maximum in the amount of rain. Thus Dutch Guiana possesses a great rainy season from April to June, and a lesser one from the middle of December to the middle

of February. The rain drops of these and other tropical regions are remarkable for their magnitude, and produce a very unpleasant sensation on the naked skin. In the East Indies, where monsoons blow instead of trade winds, there are varying conditions of rain, the rainy season on the eastern coast occurring at the time of the north-east monsoon ; that on the west coast at the time of the south-west monsoon. The rainy region of the calms does not possess any periodical rain. In some regions of the earth rains seldom, if ever, occur ; among these are Egypt, the desert of Sahara, the high plains of Persia, northern Arabia, a part of Thibet, of Mongolia, &c. This is especially the case with the extensive arid and barren plains out of the tropics. The great heat and dryness of the countries is to be considered as the cause of this deprivation. Even on the high seas in those countries, where the trade winds blow regularly, rain is very rare, and the sky almost always clear. Rain is more abundant in the vicinity of mountain ranges on the warm plains of Asia and Africa. When, for instance, the vapors of the Mediterranean are carried south and east by a north wind, they become heated in their passage, and are thereby further removed from the condition of saturation. To this they again approximate by rolling up the slopes of the high mountains, and thereby coming into colder regions. Mountains everywhere exert a great influence on rain, the gathering of clouds about a mountain top being generally the precursor of approaching rain.

With regard to the condition of Europe in respect to rain, we find in Portugal a country where this is almost entirely absent during summer. North of the Pyrenees, however, copious showers occur in greater or less abundance throughout the whole year. To the north then of the Pyrenees and the Alps, we may distinguish two groups of climate, called by Kaemtz the middle European and the Swedish. In the former rain generally accompanies westerly winds, in the latter easterly, the westerly winds losing their water in crossing the crests of the Scandinavian mountains. St. Petersburgh and Moscow appear to lie on the confines of the two regions of climate, since there is a prevalent wind at neither of these places. In passing from the western coast of England to the interior of Europe, we shall find the annual amount of rain, as also the number of rainy days, to decrease continually. Calling the annual amount of rain at St. Petersburg unity or one, then on the coast of England this same amount is 2.1, in the interior of England 1.4, on the plains of Germany 1.2 ; although particular places may present considerable deviations from these proportions. Thus in western and southern England the annual fall of rain amounts to thirty-five inches, while in Kendall it is fifty, in Dover forty-four, in Bristol twenty-two inches ; in middle and eastern England it is on an average a little over twenty-five, in Dumfries thirty-four, and in Glasgow only twenty inches. In France and Holland it is about twenty-four, and in Brussels only eighteen inches. In Tegernsee it is forty-four, in Augsburg thirty-seven, in Carlsruhe, Ulm, and Göttingen, twenty-five, in Manheim and Ratisbon twenty-one, in Prague fifteen, in Würzburg fourteen, in Erfurt only twelve and a half inches. In St. Petersburg it is seventeen, in Abo twenty-four, in Buda sixteen, in Copenhagen seventeen,

and in Stockholm nineteen inches. In the mountains of Norway, which have a very different climate, and are celebrated for their copious rains, the annual fall amounts to eighty-three inches. At Mahabuleshwar in India, on the western slope of the Ghauts, it is 283 inches, at Matouba on the Island of Guadaloupe 274, at Basseterre on the same island and at Anjarakandy in the East Indies 116, at Coimbra in Portugal 111, on the Island of Granada 105, in St. Domingo 101, at Havana 86, on the coast of Sierra Leone 81, at Bombay 73½, at Calcutta 71, and at Rio Janeiro 56. From these data we perceive that only a few places within the tropics exhibit a greater quantity of rain than mountains. The average number of rainy days, by which we understand all on which rain occurs of whatever duration, increases in Europe from south to north, amounting in southern Europe to 120, in central Europe to 146, and in northern Europe to 180; at Buda 112, at Warsaw 138, in Germany about 150 (Carlsruhe 174, Tegernsee 170, Munich 149, Stuttgardt 127, Ratisbon 115), about the same in England, France, and the Netherlands (Rotterdam 187, Paris 160, Poitiers only 99, at St. Petersburg 168, at Moscow 205, &c., &c).

The distribution of rain throughout the year varies much in different countries; in central Europe, which has a continental climate, summer rains have the preponderance, while in southern Europe this belongs to the winter and autumn. On the west coast of England the winter rains are more considerable than the summer, while in the interior this condition of things is just reversed. In the western parts of Scandinavia the winter rains are very copious, in Sweden they are almost entirely wanting, so that this country exhibits a transition from a sea to a continental climate so rapid as to have nowhere else its parallel. The rain of the warm seasons of the year is generally the most copious. Thus, taking the rain falling on a winter's day as unity or one, the amount falling in summer will be indicated in the following mean quantities: in England, 1.07; western France, 1.03; central France, 1.57; Germany, 1.76; St. Petersburg, 2.17. The preponderance of the summer rain is thus seen to increase as we go east. In England and on the coast of France the average fall of rain on the autumnal rainy day amounts to two lines and three quarters for the former, and two lines and a quarter for the latter; in central France a summer's rain is about 2.41, in Germany 2.33, and in St. Petersburgh 1.67 lines. The same laws, with respect to the predominance of coast rains in winter and central rains in summer, appear to apply also to other parts of the world.

Rain-water collected after a considerable amount has fallen, is almost chemically pure, and may be used in many cases instead of distilled water; yet it frequently contains slight amounts of certain mineral substances, especially chloride of sodium, generally combined with some lime. Traces of a somewhat greater quantity of salt are observed only on the coast and a slight distance from it, although most of the watery vapor contained in the atmosphere has ascended from the sea. Cases not rarely occur where various substances from the animal, vegetable, or mineral kingdom, either alone, or more frequently mingled with rain or snow, appear to have fallen

from the sky. This is not the place for a closer investigation into these supposed showers of *blood, fruits, sulphur, fishes, toads, stones*, &c.; this much is certain, however, that in all cases, excepting in that of aerolites properly so called, these objects have been elevated by violent aerial currents, carried to a considerable distance, and then dropped on the abatement of the storm, provided, however, that a descent from the atmosphere has actually occurred.

Of Snow.

The rain of higher latitudes is most frequently presented in the form of *snow* by the freezing of the rain-water in the air. In temperate countries this appears to freeze when the temperature is still some degrees above the freezing point, while in more southern climes it hardly takes place even when the thermometer sinks below 32° F. The shape of the particles of snow is exceedingly interesting; they occur generally as six-sided stars, consisting of needles combined at angles of 60° to 120° with each other. According to Scoresby, who has instituted the most careful observations on this subject, there are five principal forms of snow crystals: 1st. Crystals in the form of thin plates; these are most abundant. 2d. Surfaces or spherical nuclei with ramifying branches in different planes. 3d. Fine points or six-sided prisms. 4th. Six-sided pyramids; occurring but rarely. 5th. Prisms, tipped at one or both ends with a thin plate. Some of the most interesting figures observed by Scoresby are represented in *pl.* 23, *figs.* 4–23. The complete and regular crystals of snow appear only during severe cold. Should the temperature be several degrees above the freezing point, there will be a mixture of snow and rain; the crystals stick together, forming flakes of extraordinary size, which, however, are very irregular in shape, and soon melt.

In the torrid zone snow occurs only at great heights above the level of the sea, this elevation at the equator amounting to 11,000—12,000 feet. The highest mountain peaks, in all countries, if they reach above the snow line, will often have snow when rain is falling below them. In Europe the region of snow first commences in central Italy, while in Asia and America it descends much further south. The isothermal line of 59°F., which passes through Florence, may be taken as the commencement of the region where snow falls in the lowlands. At a mean latitude, and at a moderate height above the level of the sea, snow generally falls from an overclouded sky, when the weather becomes somewhat milder after severe cold, and at a temperature higher than the severest winter cold. It is an error, however, to suppose that it cannot snow during very severe cold. The latter occurrence is not rare in Germany, and Kaemtz observed snow to fall at Halle when the thermometer stood at from 5° to 1°F. After snow the weather sometimes becomes warmer, sometimes colder, more frequently the latter, and the ensuing cold is severe in proportion to the diminution of temperature during the snow-fall itself.

In Germany, and other countries nearly of the same latitude, snow generally falls in a quiet atmosphere; sometimes, however, and particularly in February, the falling of snow is accompanied by tempestuous weather. The wind in such cases frequently passes during the storm from west or south-west to north, and after the fall, cold weather with a clear sky sets in. On high mountains, and in mountainous regions, the falling of snow is often accompanied by winds which are not far behind the most violent storms in intensity, hence they are called *snow storms*. The snow storms of the Alps, so dangerous to travellers, are well known to all. At higher latitudes these storms occur at a less elevation, particularly in Norway and Kamtschatka, where they are called *Purga*. That such snow storms ought to be ranked with thunder storms is shown by the electrical condition of the atmosphere, and by the lightning which not rarely accompanies them.

The quantity of snow deposited differs with the year and country, being very variable for slight elevations above the level of the sea. More snow falls in valleys and woody districts than in the level land. The snow increases from the isothermal of 59°F. in the north, to the isothermal of 41°F. which passes by Drontheim; it then diminishes, since in the high northern latitudes the air is too cold to contain much moisture.

The quantity of water which may be obtained by melting snow differs greatly at times. During severe cold and northern or north-eastern winds, the snow is very loose and balls together with great difficulty, indicating the existence of little water. In general, the snow is lighter the more there is to be of it; hence the proverb, "much snow little water, little snow much water," is well founded. According to De La Hire, water is $3\frac{1}{2}$—12 times denser than snow; according to Celsius, $2\frac{4}{5}$—11 times; according to Van Swinden, $5\frac{1}{2}$—19; according to the more recent investigations of Quetelet, $2\frac{4}{5}$—18 times. In general, the density of snow may be assumed at $\frac{1}{9}$—$\frac{1}{10}$. Freshly fallen snow is always the lightest, gradually becoming firmer by its own pressure, and finally acquiring an icy crust by the melting of the superficial layers and subsequent freezing of the water. A considerable and quite appreciable diminution in the amount of snow on a given surface may be observed after it has lain a good while in a dry atmosphere. It is well known that snow, by its badly conducting power, acts as a preventive to the direful influences of the freezing of the ground.

Snow water is generally pure, being only exceptionally mixed with foreign ingredients, for which reason it is of no especial use to vegetation, being rather prejudicial on account of the coldness. The beautiful red color of snow first observed by Saussure (1760) in the Alps, owes its redness to minute algæ (*Protococcus nivalis*). Green snow is caused by *Protococcus viridis*.

Of Hail.

Hail, one of the most peculiar phenomena in meteorology, is divisible into two principal classes: 1st. *Sleet*, composed of round granules, generally

not more than two and a half lines in thickness, always opake, and of snow-white color, occurring in wintery weather. 2d. *Hail*, properly so called, consisting of granules of spherical, paraboloidal, or pyriform shape, varying in size from a cherry-stone to a walnut. These have generally a point, opposite to which is a hemispherical segment, and in their centre is an opake nucleus of one half to two lines in diameter. This species occurs generally in summer, in connexion with thunder and lightning. The two kinds, however, according to Kaemtz, differ only in size. As a third and very rare species Arago considers those granules which never have a nucleus of snow, and differ from sleet of equal size by being transparent. These are unquestionably produced by the freezing of drops of rain in falling from a cloud into a stratum of colder air.

The form of true hailstones is very various; generally they are rounded, sometimes flattened or angular. Delcross supposes the most common form to be a three-sided spherical segment, produced by the shattering of larger spheres. Hailstones of different forms are represented in *pl.* 23, *figs.* 24–35. The internal structure is almost as various as the form; sometimes alternations of transparent and opake strata are observed. The diameter of simple hailstones at a mean latitude, according to Muncke, is not over one and a half or one and three fourths inches, larger masses appearing to be produced by the aggregation of individual stones. Instances of hailstones, the size of hens' eggs or larger, are not rare in some parts of the world. There are cases on record of vastly larger hailstones than those just mentioned; most of these, however, are of a very fabulous character. Thus in 1719 hailstones fell at Kremo weighing six pounds, and at Namur, in 1717, weighing eight pounds. According to Wallace, pieces of ice a foot thick fell in the Orkney Islands in 1680; in 1795 pieces of ice, six to eight inches long, and two fingers thick, fell in New Holland. According to public prints, a lump of ice fell in Hungary on the 28th of May, 1802, three feet long, three feet broad, and two feet thick, estimated to weigh 1100lbs. In the latter part of the reign of Tippoo Saib, a lump of ice the size of an elephant fell near Seringapatam. In all these cases the mass of ice most probably consisted of an aggregation of single lumps frozen together on the ground. It is only rarely that foreign substances have been found in hailstones. In 1755 these fell in Iceland containing sand and volcanic ashes; in Ireland, in 1821, hail with a metallic nucleus, recognised as sulphuret of iron; in 1824, in Siberia, hail containing octahedrons resembling auriferous pyrites. According to the earlier observations, small pieces of chaff are often found in hail.

Hail generally falls during the day, although the idea that it never falls by night is erroneous, there being well authenticated cases to the contrary. It is very probable that the rarity of night hail is only apparent, not real, and owing to the greater difficulty of observing such phenomena during the darkness. It has already been mentioned that the smaller hailstones generally fall in spring: in Germany in April, during that condition of the weather known as April weather. Short showers of cold rain then alternate with warm sunshine, and with the rain there fall either single hailstones,

or the shower begins with single rain-drops followed by hail, the whole again concluding with rain. This alternation sometimes occurs in May and June, rarely in July, and perhaps never in August and September. Not unfrequently sleety hail is mixed with snow, either at the beginning, or more frequently towards the end of winter, in February or March. Fine granular hail frequently occurs on high mountains, where regular hailstones seldom are seen ; thus on the higher Alps Saussure found twelve falls of the former to one of the latter.

The real hail storms belong to the summer season, and are accompanied by the severest thunder and lightning. They are therefore most frequent in June and July, rarer in May, August, and September, and seldom experienced in April and October. Storms of this kind generally arise after clear calm weather, accompanied by long continued oppressive sultriness. The hail clouds appear to sweep very low, with their edges jagged, and their lower faces presenting irregular projections, the parts yielding hail generally forming remarkable white streaks, the rest of the cloud being very dark. The barometer and the thermometer sink rapidly, the latter sometimes as much as 77° F. A peculiar rustling in the air announces near and heavy hail clouds ; subsequently a darkness ensues not dissimilar to that produced by an eclipse of the sun. The hail itself lasts but a few minutes, with short interruptions, and generally accompanied by thunder and lightning, the duration being rarely over fifteen minutes, which, however, is often sufficient to cover the ground with a thick bed of ice. Hail storms move with great velocity ; the one which occurred in France in 1788, so remarkable for its great extent, traversed the country at the rate of 38.8 Paris feet in a second, or forty geographical miles in an hour. The force with which the hail falls is very great, and, indeed, greater as the wind is more violent. Men are not seldom injured and even killed, a calamity which occurs quite frequently to small animals. Window-glass is very often broken, and even the roofs of houses and the branches of trees are at times unable to resist the terrible visitation. The injury produced in fields, gardens, &c., is often almost irreparable, as in the storm of 1788 in France, which devastated 1039 parishes, and caused a loss to the amount of more than twenty-five millions of francs. The quantity of hail which falls is rarely measurable with any degree of exactness, owing to the rapid melting produced by the accompanying rain, and the more elevated temperature of the air or ground. A depth of six inches is sometimes attained, although this very rarely occurs, at least in our latitude. A torrent of rain generally follows a fall of hail, lasting rarely more than half an hour. The area traversed by the hail is generally but small in width, often but a few hundred or thousand feet, rarely over a mile ; the length of this area, again, is sometimes very great, amounting to over 400 miles in the storm just mentioned.

In the tropics hail rarely occurs excepting at great elevations ; in the far north, again, large hail is very seldom seen. In general the tract of hail proper is confined to the region between 30° and 60° degrees of latitude, and to elevations under 6000 feet. Even within these limits there are

countries where hail seldom or never occurs, as in some valleys of Switzerland, especially in the Valais, and in most of the valleys extending east and west. In the low lands at the foot of high mountains, hail is more abundant at a certain distance from the mountain than nearer or more remote. The same region is sometimes ravaged by hail storms for several years in succession, and afterwards again spared for a considerable time. From the comparisons of Kaemtz, who assumes but one kind of hail, there occur in France every year from ten to twenty hail storms (the most in spring, the fewest in summer), over five in Germany, five in Rome, and three in the interior of Europe.

Of the many propositions for preventing hail by the use of hail conductors none have yielded any practical results. The methods suggested may exert their influence in three ways: either by drawing off the electricity, by mechanical agitation of the strata, or by a chemically decomposing influence on the composition of the atmosphere. Hail conductors, or rods of the first kind, were proposed by Guenaut de Montbeillard in 1776. In 1820 La Postolle, and after him Thollard, recommended hail conductors of straw ropes, attached to pointed rods, or of straw ropes with a metallic wire interwoven. Curiously enough, these methods were much followed without the least benefit flowing from them. At the present day most meteorologists are agreed that there is no certain, or at least practical method for preventing the occurrence of hail storms.

6. *On the Optical Phenomena of the Atmosphere.*

The air, although among the most transparent bodies in nature, is not perfectly so. Were this the case, its individual particles would reflect or scatter no light, and even by day the canopy of heaven would appear perfectly dark or black, with the exception of the space occupied by the sun and stars: sudden and total darkness would likewise ensue immediately on the setting of the sun. The general illumination of the heavens, and of objects not immediately reached by the direct solar rays, as also the gradual transition from daylight to the darkness of night, can only be explained on the supposition that the air does not transmit all the light, but reflects one part of the light traversing it, and absorbs another. The latter circumstance produces an enfeebling of the light, as we may readily perceive on examining remote terrestrial objects. In such an examination we find objects becoming more indistinct with increasing distance, vanishing at last altogether. The diminution of the angle of vision has of course something to do with this result, but not everything, since the effect thus produced varies at different times.

An instrument called the *diaphanometer*, invented by Saussure, is used to determine the transparency of the atmosphere. This savant painted black circles of different diameters on a white ground, and then removing from them, determined the distance at which they disappeared; this served as a measure of the transparency in question. In the higher regions of the

atmosphere, this enfeebling of light is much less than at the surface of the earth, on account of the greater rarity of the strata of air. Watery vapor, and the smoke and dust carried aloft in various ways, exert great influence on the transparency of the air. Gaseous vapor appears to increase in a very high degree this transparency, as oil does that of paper. Nevertheless in opposition to this theory, the dry air in the interior of continents, as in Siberia, Persia, Africa, and Brazil, is remarkably transparent. Condensed vapor may diminish or even entirely destroy the clearness of the atmosphere.

The remarkable *blue* of the sky, or rather of the atmosphere, is not of the same tint in all places and at all times. In and about the zenith the heavens generally appear the darkest, decreasing thence to the horizon. This color is very dark blue when seen from high mountains. It is darker in the torrid zone than in higher latitudes; in Italy and Greece more so than in Germany; above the sea more than over the land in the same latitude. To compare the various shades of blue, and to determine them according to a given scale, Saussure invented the *cyanometer*. This consists of a circular plate, on whose periphery, white and black, and between the two, fifty-one different shades of blue are painted. The principle on which this scale is constructed depends upon the fact that the difference of color of two surfaces painted with different shades of the same color, vanishes entirely at a certain distance. Two blue surfaces differ, now, by one degree when the difference of their color is insensible at a given distance (according to Saussure, that at which a black circle of $1\frac{3}{4}$ lines in diameter in his diaphanometer vanishes entirely). To determine the blue of the sky at a given place, the cyanometer is held between the eye and the spot until the color corresponding to the former is found on the latter. Saussure and others found the color of the zenith in Chamouny to be nineteen, in Geneva twenty-two and a half, on the Col de Géant thirty one, and on Mont Blanc thirty-nine degrees. Parrot has proposed the use of colored disks to determine these shades. Arago has suggested the use of polarized light for this purpose; his method, however, is not likely to be much employed. The reason of the blue color of the sky depends, according to Newton, on blue being the color of the particles of air, these absorbing all the other rays and transmitting the blue. If this hypothesis were correct, then distant snow-clad mountains would appear blue, which is not the case. The reason of the varying blueness of the sky is to be ascribed to the influence of vesicles of vapor, which may be proved by the fact that on the sea-coast the sky is darker on the land than on the sea side of the zenith, at the same zenith distance. The maximum of blue appears generally to be presented some time after the culmination of the sun.

Besides the blue color, the heavens frequently present at the rise or setting of the sun, a beautiful redness, the so-called *morning* and *evening red*, whose color changes into innumerable shades from yellow and bright red to dark red. The evening red (generally more abundant and brilliant than the morning) is most beautiful when the sky is of a very deep blue. The sun then at his setting appears very luminous, although not very red;

even before sunset the whole horizon appears reddish yellow, this increasing until just as the sun is going out of sight: a remarkable reddening simultaneously presents itself in the eastern heavens, opposite to the sun, reaching its maximum as the sun goes down. Just after sunset, a light purple red is often seen shading the whole blue of the sky, and with the increasing descent of the great luminary the eastern heavens become dark, and there is often observed there a more or less evident segment of dark blue, whose highest point is directly opposite to the sun, and which is generally sharply defined (sometimes by a white or yellow border). The lustre of the western skies passes at the same time from the golden, more into the red; this portion, however, not extending very high. The evening red appears most magnificent when, with a deep blue sky, there are some clouds in the west. Should these be cirro-stratus clouds, they appear before sunset as grey streaks with bright borders, the latter becoming afterwards golden yellow, and often fiery red. Clouds near to each other are often very differently tinted, some dark red, some yellow; this depending on a higher or lower position in the atmosphere.

This redness of the evening and morning sky has been generally explained by saying that the air transmits more readily the yellow and red rays, while it reflects more readily the blue. The sun's rays having to traverse a considerable space through the atmosphere at his rising and setting, the air has an opportunity of acting to most advantage on his light, and of decomposing it, absorbing most of the blue. More recently, Forbes has attempted to show that this explanation cannot be correct, since the blue of the sky, strictly speaking, is not complementary to the evening red; the latter he explains by the watery vapor contained in the air, which, when perfectly gaseous, is quite transparent and colorless, but in its passage to its condition of condensation, transmits only the yellow and red rays.

The evening red and the morning grey are generally considered to be signs of fine weather: that the morning red is indicative of bad weather is by no means so universally correct. When the evening red is tinted with a soft purple red it certainly indicates continued fine weather, which is not the case with a whitish yellow, a very red, or a dull red evening sky.

Of Twilight.

Closely connected with the phenomena of the morning and evening red stands the *twilight*, that gradual passage from daylight to darkness, and the reverse. Although the term twilight applies to both cases, yet the latter only is meant when we speak of the *dawn*. When the sun shines on the upper strata of the air, after ceasing to illumine the surface of the earth with his beams, a certain portion of the light is reflected towards the earth, thus producing a considerable degree of light. The beginning of morning or the end of evening twilight is marked by the disappearance or appearance of stars of the sixth magnitude. The depth at which the sun stands below the horizon at the beginning or end of twilight is differently estimated,

varying from sixteen to twenty-four degrees, generally eighteen. As the sun's orbit in higher latitudes is very slightly inclined to the horizon, twilight there lasts longer, while at the equator itself, where the sun's orbit is perpendicular to the horizon, it is shortest, the sun occupying the least time in traversing the eighteen degrees just below the horizon. To find the duration of twilight at any place and day, it is only necessary to ascertain how much time is required by the sun in that part of its orbit to get eighteen degrees below the horizon. There will be two periods of shortest twilight in each year at every place. In estimating the actual and not the astronomical length of twilight, however, it is necessary to remember that the varying amount of moisture in the air will influence the reflection or dispersion of the solar rays very materially. Thus if the particles of vapor exist abundantly at a great elevation, and the lower strata of air be very transparent, twilight may last an uncommonly long time. Between the tropics twilight is always of very short duration ; in Cumana, on the coast of Sierra Leone, at Paramatta, &c., it lasts only a few minutes; in Chili, during the dry season, only a quarter of an hour, although the time calculated, according to the preceding principles, would allow an hour and twelve minutes at the equator itself, even at the time of the equinoxes. The polar regions rejoice in very long twilights, at whose beginning and end the sun is probably thirty degrees below the horizon.

Various Phenomena of Atmospheric Refraction and Reflection.

The twinkling of the stars, frequently more conspicuous at one time than at another, is produced by the agitation of vapor by aerial currents, and may justly be considered, when very remarkable, as a presage of wet weather; it depends upon the difference in the refraction of light in warm and cold, wet and dry air. It is sometimes accompanied by a change of color; in the fixed stars it is incomparably more evident than in the planets. Stars in the vicinity of the horizon sparkle more than those nearer the zenith, these frequently appearing nearly quiet. The twinkling is greatest when currents of unequal temperature move in contact, mixing partially; for this reason it is not the same in all regions, being visible during the dry season in the tropics only near the horizon, and but feebly there. In higher latitudes it becomes very striking during severe cold and a clear sky.

The so-called *drawing of water* is another phenomenon falling under this head. This (*pl.* 27, *fig.* 4) takes place when, while the sky is well covered with broken clouds, the sun stands behind a rain cloud and shines through openings in it. By the reflection of drops of water, particles of dust, &c., light streaks are presented, which, while apparently converging towards the sun, in reality are parallel. This appearance is seen more frequently in summer than in winter, oftener when the sun is low in the horizon than when he stands higher, and may generally be taken as indicative of approaching rain.

Rays proceeding from the sun and other luminous bodies are refracted on their entrance into the atmosphere. As this, however, is composed of innumerable strata, increasing in density to the surface of the earth, these rays must be continually refracted, and thus move in curved paths which are concave to the earth. The consequence of this is, that unless a heavenly body is actually in the zenith, where no refraction can take place, its place, as seen by our eyes, will be higher than its true place. The amount of this displacement increases from the zenith to the horizon. Near the horizon it is half a degree, at an elevation of 45° it is one minute, and at 75° only one fourth of a minute. The sun (as also other luminaries) is thus seen in the morning before his actual appearance above the horizon, and in the evening after he has already set. The day, then, is lengthened by refraction, this lengthening amounting during the longest days to eight or nine minutes in Germany, and at higher latitudes to much more—to days and weeks in the polar regions. The same cause produces the oval form of the sun when just above the horizon, his lower limb being more refracted than the upper, his vertical diameter being thus abbreviated while the horizontal suffers no change; the result is the apparent elongation of his disk. A similar effect is produced on terrestrial objects, for which reason we distinguish a *terrestrial* from an *astronomical* refraction.

Refraction varies at different times, owing to its dependence on a variable condition of the atmosphere. For this reason the horizon does not appear always in the same place; it seems lower when the air at the surface of the ground is warmer and rarer than at an elevation of some feet; and higher when the ground is colder. Should the ground be strongly heated we shall observe a lively shaking or tremulous motion of objects, owing to the existence and combination of air strata of different densities and unequal refractive powers.

When the sun is very hot and the air calm, the lower strata of air, heated by the sun, often have a less density than those above them, without changing their position. In *pl.* 24, *fig.* 19, let *ab* be the horizontal surface of the earth, *h* an elevated point or object; let the eye of an observer be at *p*. He will see first a direct image of the object, *h*, in the direction *ph*, in which the rays, being only slightly deflected from a right line, will only produce irregularity in the outline of the image. Other rays, however, coming from *h*, follow the path *hilmnp*, since the ray, *hi*, which traverses strata *c*, *c'*, *c''*, *c'''*, of decreasing density, is continually refracted from the perpendicular, becoming more and more acute-angled to the horizon After traversing a sufficient number of these strata it ceases to be refracted any longer, and then it is reflected, reaching the eye in the direction *mnp*. The observer will thus see an inverted image of the object, *h*, in the direction *pz*.

Phenomena of this kind generally occur in hot countries, especially in deserts, as, for instance, in Egypt, where the French army was frequently bitterly deluded by this *mirage*. In Lower Egypt the ground forms a vast and perfectly horizontal plain, exposed to the overflow of the Nile. The villages are there built on small hills on the bank of the river, or at some

distance from it towards the desert. The air is generally calm and pure; early in the morning and in the evening, therefore, objects appear in the natural positions and distances. But when the ground becomes heated by the ascending sun, and with it the lower strata of the air, a tremulous motion will be observed in the distance, such as is seen during a hot and calm summer day, or such as takes place sometimes over a heated stove. Should the air be perfectly calm, so that these inferior strata are not disturbed in the least, a direct image of all the villages and other elevated objects will be seen in the distance, and under them a reflected image, just as if they were situated on the banks of a quiet lake. The ground thus appears to be covered with water, in which the hills stand like islands. On approaching nearer, the apparent outline of the water recedes, always keeping at a certain distance from the observer. This phenomenon is frequently referred to by Arabian authors, as also in the Koran, under the name of *Serab*. It is likewise known in Middle India, where it is called *Chittram*, *Dessasur*, &c. In many cases, instead of an inverted image under the distant objects, only a bright streak of light is perceived, this image being too small to be perceptible. Thus we sometimes see the ascending sun apparently floating in the air, especially when the eye is near the ground.

Even at sea, and under quite different circumstances (namely, when the ground is colder than the contiguous strata), similar phenomena present themselves. In general we may distinguish three different classes of these phenomena. To the first belong those cases where distant objects, which generally are concealed by the curvature of the earth, become visible for a short time. This occurs both by land and sea, especially in the Northern Ocean. To the second class belong the cases in which distant objects appear surrounded by water, a phenomenon occurring in extended plains, and not confined to warm countries, but even found in the Steppes of Russia. In the third class are placed those complicated appearances in which the object appears double, and sometimes even three-fold; here an upward or downward reflection is distinguishable, according as the secondary inverted image appears above or below the primary. Thus, not unfrequently, vessels just visible in the horizon are seen double, a second inverted image being observed above an upright one, the mast tops of the two pointing towards each other (*pl.* 24, *fig.* 20). Again, in the case of a vessel whose masts just loom above the horizon, we may see two images, one erect, and beneath this another inverted (*fig.* 21). The latter (downward) reflection rarely occurs on land. Professor Vince once saw at Ramsgate, on a sultry evening, after a very hot day, the mast of a vessel projecting above the horizon, at some distance above it the image of the whole ship inverted, and above that again an erect image, the two latter separated by a strip of sea. When the vessel approached, the upright image vanished first, then the strip of sea, and finally the inverted image.

The time-renowned phenomenon of the *Fata Morgana*, observed on the coast of Calabria, and especially at Reggio, belongs in this place. At a

certain time houses, palaces, colonnades, groves, hedges, &c., are seen above the sea, the whole being but the aerial reflection of the city of Messina and its environs. Most of the earlier descriptions of this wonder are exceedingly exaggerated and highflown.

Monge, Vince, and Biot, have, more than any other philosophers, been occupied in investigating these interesting and remarkable phenomena. The latter has shown how, under certain circumstances, a line, *btc* (*pl.* 24, *fig.* 22), may be supposed drawn from a distant point, *b*, beneath which all objects will be invisible to an observer at *c*, while of all objects above this line two images will be seen, one direct above the line, and another inverted below. Thus a man walking from the observer would successively present the appearances of *fig.*22.

Sometimes the unusual or secondary images lie neither above nor below the primary, but at one side of it. An apparition of this kind was seen by Soret and Jurine, Sept. 17, 1820, on the Lake of Geneva (*pl.* 24, *fig.* 23). While standing in the second story of a house on the bank, they looked through a telescope in the direction *gp*, at a ship, *p*, which was two miles off, and sailing towards Geneva. While the vessel came successively to *cqrs*, they noticed to the left hand distinct images, *q'*, *r'*, *s'*, which separated more and more from the direct or primary image of the vessel with increasing approximation. The air over the lake on the eastern bank, ABC, at that time had been a good while in the shadow cast by the mountains of Savoy, while the left side was already heated by the sun. The plane of separation between the cold and warm air was thus vertical for a moderate height above the water. The sailing of the vessel just along the confines of the two regions produced the phenomenon in question

On the Rainbow.

Of all the optical phenomena of the atmosphere the *rainbow* is perhaps the most beautiful. It is seen when a spectator with his back to the sun looks in the opposite direction towards a shower of rain proceeding from an illuminated cloud. Two different bows are generally seen, one above the other, with their colors in the reverse order; the lower of the two is generally most brilliant. Suppose a straight line, OP (*pl.* 26, *fig.* 12), drawn through the sun and the eye of the observer, and a vertical plane passed through this line. Draw through O a line O*x*, so that the angle PO*x* amounts to 42°, then rain-drops which lie in the direction O*x* will send colored rays to the eye, and as this is the case with all drops which lie in the surface of a cone formed by rotating the line O*x* about OP, the eye will see a light circle of about 42° of radius. The centre of the circle lies where a line produced from the sun through the eye of the observer cuts the opposite sky, or where the shadow of the observer's head would fall. The light of the sun entering the drops of water from above is refracted to the opposite internal surface, thence reflected to the lower part of the drop, and emerging reaches the eye of the observer, if he be at the proper

angular distance. The light in these successive refractions and reflections becomes decomposed, and as each color has a different refractive power, it follows, that to see all the colors (violet to red) from the same drop it will be necessary to take up successive positions, so that the angle POx may range from 40° 17′ to 42° 2′. If, however, as is actually the case, we have a series of drops, one above the other, and as the angle made between the axis of the box and the line from the eye to the individual drops, amounts to from 40° 17′ to 42° 2′, we shall, without changing our position, observe all these colors. The breadth of the arc is about 2°, the colors fading one into the other, and succeeding in the order of the spectrum, the red being uppermost. When the sun is veiled by mists or clouds the bow may appear simply as a light colored arc. The nearer to the horizon the sun stands the greater is the arc described; when the sun is in the horizon the bow is a semicircle. An observer under favorable circumstances may, from an elevated position, see more than a semicircle, and completely circular bows can often be observed in the spray from fountains, waterfalls, &c. When the sun is 42° above the horizon no bow will be visible.

Besides the primary bow just described, a secondary bow may almost always be observed outside of the first, but still concentric with it, and with the colors in the reverse order. The red is here the inner color, and the violet the outer. The colored bands are broader but weaker than the corresponding ones of the primary bow. This secondary bow is produced by the colored rays from drops at such an elevation that they just reach the eye after undergoing two refractions and two reflections, while in the first case there are two refractions and but one reflection. The same drop cannot furnish at a given instant to the same position of the observer colors belonging to both bows, although it may in different stages of descent, or to different observers. The angular position of the second bow is between 50° 59′ and 54° 9′, with respect to the axis or the line from the sun through the eye to the spectator; there may be more than two bows resulting from rays that have undergone more than two reflections, but the light becomes finally so feeble as to render it impossible in ordinary cases to distinguish them.

It is evident from the preceding principles that a rainbow may appear in the west in the morning, in the east in the evening, and in the north at noon; never in the south. Also, that every observer sees his own rainbow, and that this changes for him with every successive instant. A drop of water can only play its part to a fixed observer who sees two bows during two periods of time, the first in passing the limits of the upper bow, the second in passing across the second.

Sometimes other colors are added to the violet of the primary bow, as, for instance, a second green and second violet; red also is sometimes perceived. This same repetition of colors may also be observed occasionally on secondary bows. The cause of these irregular colors is not yet satisfactorily explained.

Some different rainbow formations are exhibited in *pl.* 26, *figs.* 10 and 11. Should the image of the sun be reflected from the surface of extended calm

water into a rain cloud, this reflected solar image, for an observer sufficiently near the water, may produce the same effect as a sun standing below the horizon, and also producing a bow, which then regularly intersects the former. The manner in which this intersection is performed depends upon the elevation of the sun. Sometimes four rainbows are seen, where both the sun and its image produce two bows each. The reason that this phenomenon is not visible on the sea is, that the surface is rarely smooth enough, and the image of the sun in the waves is generally too indefinite.

A rainbow appearance is sometimes seen in the spray of the sea, or in the dew-drops of a meadow, where the curve is generally of an elliptic, parabolic, or hyperbolic shape. These bows, as also those seen in the mist of waterfalls, &c., are produced by the same causes as actual rainbows.

Lunar rainbows occur but rarely; sometimes they are colored (as at Forchheim near Freyberg in Saxony, November 22, 1847), but more generally white or yellowish, the feebleness of the moon's light not permitting the colors to be distinguished.

Of Halos and Parhelia.

An additional class of very complicated phenomena, likewise dependent on atmospheric reflection and refraction, is presented by *halos* and *parhelia*. We must distinguish two kinds of halo, lesser and greater, which, in appearance as well as in constitution, are completely different. The *lesser halo* is a colored ring a few degrees in diameter, seen around the moon, more rarely around the sun, when the sky is covered by a pale veil of very thin cloud (*pl.* 25, *fig.* 9). The red predominates in these rings, and sometimes several concentric ones are observed separated by interspaces, in which green may be detected. The dazzling action of his rays is the principal reason why this form of halo is seldom noticed around the sun. They may, however, be very frequently detected by assuming such a position as enables us, without looking directly at the sun, to see the contiguous portions of the heavens, or by observing the reflection of the sun in still water, or in a plate of glass blackened at the back. In June, 1692, Newton distinguished three different series of rings at one time: in the first the succession of color, commencing nearest the sun, was blue, white, and red; in the second purple, blue, green, bright yellow, and red; in the third, blue and red. The diameters of the three red circles were five, nine and a half, and twelve degrees. The phenomenon is very rare in the perfect form; in general, however, it has great similarity to the glory observed on looking at the flame of a candle through a glass plate on which lycopodium has been strewed. According to Fraunhofer, the phenomenon of these halos is produced by the refraction of light, by the vesicles of vapor in the air, as also by the interference of light.

When the clouds are not so dense as entirely to intercept the passage of

rays from the sun, they all, excepting the cirrus, exhibit traces of colored rings. This phenomenon, although very frequent, is not always of equal beauty and distinctness; to observe it we may make use of the blackened glass plate already referred to. White clouds in the vicinity of the sun, with their edges parallel to the horizon, do not exhibit very well defined rings, but rather lively prismatic colors in the shape of streaks, ten and more degrees from the sun, and parallel to the horizon; these are generally green in the middle and surrounded by a red border.

The so-called *halo of glory*, seen about the human shadow when cast on the grass, or upon a surface curved with dew by a declining sun, is a curious appearance produced by the reflection of light from the dew-drops, or from the cylindrical smooth stems of the straw or grass; as the entire lustre depends on the position of the eye, the sun, and the reflecting surface, each one sees only the glory about the shadow of his own head, that of others, even though very near, being invisible.

Among halos is to be counted the appearance produced where the shadow of the observer is cast on a cloud, his head appearing surrounded by colored rings. The first observation of the kind was made by Bouguer in the Cordilleras in the middle of the last century. He and his companions, standing on the top of a high mountain, about sunrise, saw each one his own shadow depicted on an opposite cloud, the head surrounded by from three to four brilliantly colored concentric rings, the red being outside, and the other colors following in the order of the spectrum. Around these rings was another of a white color, and about 67° in diameter. Scoresby, in his arctic voyage, frequently observed this interesting phenomenon, which, according to him, always appears when sunshine and cloud co-exist, a circumstance which often occurs in the polar regions, the thin fog which there rests on the surface of the sea extending to a height of from 150 to 180 feet. An observer at the masthead of a vessel discerns his shadow in the fog opposite to the sun, the head surrounded by four or five colored rings. Howard and several companions once observed their shadows, and that of the rock on which they stood, depicted on a cloud or fog bank sweeping below them (*pl.* 27, *fig.* 7). This phenomenon is very common in the Alps, particularly on the Rigi and on the Brocken, where it is called the *Spectre of the Brocken.*

The larger circles of twenty-two to twenty-three, and forty-six to forty-seven degrees' radius, sometimes seen about the sun and moon, are of entirely different character from those previously described. The colors of the smaller ring are generally much less lively than those of the rainbow, red, however, being recognisable on the inner edge, while the outer is very indistinct; the colors of the larger circle, which is much the rarer, exhibit more depth and purity. *Pl.* 25, *fig.* 10, represents a simple, *fig.* 11 a double halo of this character; *fig.* 12 is a simple halo combined with a colored ring or true halo. Halos about the sun and the moon are very abundant, but are generally appreciable only by means of the blackened glass plate; Kaemtz supposed that at least sixty were visible in Germany each year. The general conditions of formation are pretty much the same

in the two kinds of halos, the lesser and greater, the principal difference being, according to Kaemtz, that while cumulus cloud gives rise to the former, cirrus or very light cirro-stratus produces the latter. The two are never seen in the same cloud; when they do appear conjointly, the lesser is formed in a secondary cloud of fog.

Sometimes halos are accompanied by other phenomena, namely, by circles and arcs which pass through the sun, or by arcs intersecting each other, and exhibiting the so-called *mock suns* and *mock moons*, or *sun* and *moon dogs*, more scientifically known as *parhelia* (*pl.* 25, *fig.* 13), AB. The simplest case is where, the sun or the moon being low in the sky, a portion of a vertical circle in the shape of a column stands directly over the luminary (rarely under it). A white circle, moreover, frequently passes through the sun, often encircling the whole heavens, and parallel to the horizon, the breadth being nearly equal to the diameter of the sun. Should there be then a vertical arc above and below the sun, the latter will stand in the middle of a cross, a phenomenon but rarely observed. The mock suns appear most generally where the inner ring and the horizontal circle intersect each other, and are themselves frequently seen when the circles are invisible. They have the color of the inner ring, but are usually provided on the outside with a long shining horizontal train. The higher the sun, the more do the mock suns lie outside the intersection of the circles, and at a considerable elevation of the sun, two mock suns on each side are sometimes visible. Sun dogs sometimes occur at a distance of ninety degrees from the sun. Rarer phenomena are, tangent circles at the highest and lowest parts of the ring; tangent arcs at a distance of sixty degrees from the lowest part of the ring; a sun opposite to the true sun, and at an equal height with it; &c. (*figs.* 14–20). The phenomenon observed on June 29, 1790, by Lowitz in St. Petersburg, is to be considered as normal in its character. It lasted for five hours in an atmosphere filled with vapor; but cases of this perfection rarely occur. The most important individual parts of this celebrated illustration of parhelia were: 1st, a ring round the sun of about twenty-two degrees' radius, red within and bluish without; 2d, a second colored ring about the sun of twice the radius of the preceding; 3d, a white horizontal circle passing through the sun and encompassing the heavens; 4th, five mock suns on this circle—two of them colored with long brilliant trains a little outside of the lesser circle, two white at a distance of ninety degrees from the sun, and one white and pale directly opposite to the sun; 5th, a lively lustre at the uppermost point of the inner ring, where at times a contact arc was seen; 6th, an arc convex to the sun at the lowest point of the ring just mentioned; 7th, a colored arc, also convex to the sun, at the highest point of the greater ring; 8th, two pale arcs passing through the parhelia and the upper part of the inner ring; 9th, two colored circles touching the outer ring, whose points of tangency were about sixty degrees from the lowest point of the former ring.

All these phenomena are explicable very satisfactorily by the refraction of light passing through prismatic crystals of ice, or snow crystals floating in the air. In proof of this, the appearances in question are most numerous

in winter and in the colder countries (especially near the poles). It is a little remarkable, on this hypothesis, that they should occur in summer; but even then particles of ice may float at a great height in the air. Upward and downward currents of air are unquestionably of influence, since, after south winds have saturated the air with moisture, an ascending current carries this to such a height as immediately to freeze the moisture condensed by the cold; or a descending cold current may produce the same effect on the moisture of an inferior current. In this way we explain the very rare occurrence of halos in the torrid zone.

Of the Zodiacal Light.

About the time of the vernal or autumnal equinox, and shortly before the rising or after the setting of the sun, there is seen a whitish streak of light, tending in the direction of the ecliptic or of the zodiac (whence the name), and running out above into a point. This is called the *zodiacal light* (*pl.* 27, *fig.* 13), which in spring is seen more frequently in the western evening sky, and in autumn early in the morning of the eastern heavens. The light of this object is generally much feebler than that of the milky way, being brightest in the neighborhood of the sun, feebler towards the point, and never so bright as not to allow the lesser stars to shine through it. The shape of the zodiacal light is that of a pyramid or cone, whose base rests on the sun; more accurately, that of a very eccentric ellipse, whose variable major axis passes through the sun, and is at least five times as long as the minor. The apex seems sometimes to run out into two straight lines which form an angle of 10°—26°; the cone, therefore, appears truncated. The axis falls nearly in the plane of the sun's equator. The length, measured from the sun, amounts generally to not over 43°; sometimes, however, to 100°, and in single cases in the torrid zone even to 120°. The greatest breadth in the vicinity of the horizon varies from 8° to 30°.

In the torrid zone, where the zodiacal light stands almost perpendicularly to the horizon, it is not only more frequently seen, but is far more brilliant and remarkable than in higher latitudes. Even in the island of Guadaloupe it may be seen at any time of the year with a clear sky, while in our own latitude it is visible only in spring and autumn. Humboldt observed it on the Andes, and on the plains of Venezuela, as also at sea, more luminous than the milky way in the constellation Sagittarius, and the exhibition was more brilliant when the vaporous exhalations were projected against the light. At sea, between 10° and 14° N. L., he observed it for several weeks in summer in great beauty, and presenting a splendid play of colors: becoming visible an hour after sunset, it became weaker towards ten o'clock, and vanished almost entirely about midnight. He was especially struck by the varying brightness of its lustre: after being at its brightest, it would in a few minutes after become remarkably enfeebled, and in particular cases he thought he observed a kind of flickering and waving of the light. Our figure (*pl.* 27, *fig.* 13) represents the zodiacal light as observed by Horner, in the

Atlantic ocean, N. L. 28°, on the night of Dec. 13, 1803. At that time it was visible as a reddish lustre in the evening twilight, of fifteen degrees in height; subsequently it extended more and more even to the zenith, near which it was about four degrees broad, the whole forming a triangle, whose base resting on the horizon was from eight to ten degrees in length.

The true character of this remarkable phenomenon is veiled in the greatest obscurity. Dominic Cassini, and, after him, Laplace, Schubert, and Poisson, assumed a ring encompassing the sun and forming the orbitual path of an innumerable host of small planetary bodies revolving around the sun. According to Fatio de Duillier, the zodiacal light bears a great resemblance to that of the tail of a comet; according to Euler it is identical with this latter. Mairan, with most of his followers, supposed it to be the sun's atmosphere; Hutton referred it to the agency of electricity; Thomas Young derived it from a highly rarefied atmosphere of light revolving around the sun with a far greater rapidity than the earth. Regner, however, showed that there could be no luminous atmosphere around the sun, else it would be visible in total eclipses of the sun: he supposed the zodiacal light to be nothing else than light attracted and condensed by the illuminated hemisphere of our earth, and thus made visible at night. All these hypotheses are more or less untenable, particularly that which supposes the zodiacal light to be the luminous atmosphere of the sun, since, according to mechanical laws, this cannot be flattened more than in the ratio of 2 : 3, the greater axis being thus to the minor as 3 : 2. According to this computation it could not extend to more than $\frac{9}{20}$ths of Mercury's orbit, while the zodiacal light extends beyond the earth's orbit, and the ratio of the two axes is at least as 1 : 5, and sometimes still greater. Perhaps the theory of Humboldt as to the material origin of the zodiacal light is the most probable. He assumes a greatly flattened ring of highly rarefied matter, revolving freely in space between the orbit of Venus and Mars, and consisting of particles of ether or other matter, revolving, according to the planetary laws, around the sun, their light being either independent of or derived from the sun.

On the Fiery Phenomena of the Air.

Excluding the electric and magnetic meteors, namely, lightning and the aurora, there remain to be considered, under this head, various phenomena more or less puzzling in their character. The principal of these are the ignis fatuus, the shooting stars, and the balls of fire; the two latter probably identical in their nature.

The *ignis fatuus*, also known as *Will-o'-the-wisp* and *Jack-o'-lantern*, is the faint light or flame, generally about the size of that of a taper, which is occasionally seen to hover over the earth at a certain height in the atmosphere, and flickering here and there, sometimes vanishing almost entirely. It is at times accompanied by a slight smell of sulphur. These are most numerous in churchyards, marshy places, and other localities where dead

animals exist, this being especially the case in warm countries during summer and the beginning of autumn, just after sunset. Reliable observations by scientific men on this phenomenon are very few in number, owing to the rarity of its occurrence. The distinguished astronomer, Bessel, while travelling in a boat to Bremen on the 2d of Dec. 1807, saw, during the very dark and rainy night, several hundreds of these lights over a piece of ploughed moorland. They were mostly of a bluish color, without much motion. In many parts of Spain and Italy, especially about Bologna, and on some dry hills near Nizza, great flames are sometimes seen to ascend from the earth to a height of twelve feet. They vanish suddenly, again become enkindled, and appear to be extinguished neither by wind nor rain, changing their places with considerable rapidity. There is no doubt that many of the accounts we have of the ignis fatuus, especially those of ancient writers, are highly tinctured with superstition and fear, to which we may also ascribe the idea that on approaching the light it always recedes and leads its follower astray.

According to Volta, the real ignis fatuus consists of carburetted hydrogen gas inflamed by electricity. Gehler supposed it to be due to a phosphorescent matter generated by putrefaction. Parrot considered it as a marsh gas (probably a mixture of phosphuretted hydrogen and other gases) inflamed by the atmosphere. Berzelius asserts, however, that this theory is untenable, since the gases mix very rapidly, and the peculiar unpleasant smell of the gas just mentioned would be readily perceptible where such meteors occur. Muncke believed that in most cases hydrogen containing phosphorus in solution, if not phosphuretted hydrogen itself, must be considered as the cause of the phenomenon, but that some accounts and appearances are attributable to the phosphorescence of decaying animal or vegetable matter. In other cases, especially in warm countries, it is exceedingly probable that luminous insects, like the firefly, the glow-worm, &c., have given rise to the appearance in question.

A phenomenon of much more frequent occurrence is presented by the *shooting stars.* These luminous bodies, like stars, seem to glide rapidly across the heavens. As the subject has already been referred to under the head of astronomy, it will here be necessary to make only a few supplementary remarks.

The elevation of the shooting stars, that is, at the beginning and end of their being visible, is very various, ranging, according to the observations and measurements of Bensenberg and Brandes, from four to thirty-five miles. A series of observations made in 1823, on one hundred shooting stars, gave 4 of 1—3 miles, 15 of 3—6 miles, 22 of 6—10 miles, 35 of 10—15 miles, 13 of 15—20 miles, 3 of about 30 miles, 1 of 45—46 miles, 1 of about 60 miles, and 1 of over 100 miles. Olbers, however, considered all determinations of over thirty miles as highly problematical. Among thirty-six of the hundred just referred to, their observers estimated that twenty-six went downwards, nine upwards (the angle of inclination from 6°—68° to the horizon), and one horizontally. The orbits of most had a westerly direction, opposite to the motion of our earth in space. The average velocity

of motion is from twenty to thirty-nine miles per second, more than twice as great as that of our earth in space.

The shooting stars fall either singly or in showers. The latter occur periodically, appearing most conspicuously from the 9th to the 14th of August, and from the 12th to the 14th of November. The unparalleled fall of stars which occurred in North America during the night of November 13, 1833, in which at least 240,000 fell in nine hours, first induced Olmsted and others to suppose that a certain connexion existed between these showers and certain days of the year. The fall of meteors observed at Cumana by Humboldt and Bonpland on the 12th of November, 1799, and by others in the United States, in Greenland, and in Germany, was called to mind, as also the showers in October of 902, 1202, and 1366; on the 9th and 10th of November, 1787, in Southern Germany; on the 12th and 13th of November, 1822, in Potsdam; on the 13th of November, 1831, on the Spanish coast; and on the 12th and 13th of November, 1832, in England, France, Switzerland, Germany, Belgium, and Russia. Since then the November meteors have occurred regularly about the same time of the year. With respect to the shower of 1833, Olmsted has shown that all the meteors radiated from the same point in the heavens, this point lying in the constellation Leo. According to Encke's calculation from observations made in the United States at that time, all the stars proceeded from that point in space towards which the earth's motion was directed at the time. Olbers thinks it exceedingly probable that a recurrence of the great shower may be looked for every thirty-four years.

A scarcely less regular meteoric shower takes place from the 9th to the 14th of August. Being observed about St. Lawrence's day, it is sometimes called the *shower of St. Lawrence.* Muschenbroek, in 1762, first called attention to the abundance of these meteors in August; but Quetelet, Benzenberg, and Olbers, have more particularly determined the periodic return of the phenomenon. Other periodic showers have been indicated as occurring in April, towards the end of November, and from the 6th to the 12th of December.

Simultaneously with the shooting stars of November, 1833, were seen great balls of fire, and there is now no doubt that both are essentially identical. A common peculiarity of all fire balls is, that after being seen for a short time, they burst with a loud noise and the evolution of smoke; other than this, they are quite different at times. Sometimes they exceed in size the apparent diameter of the moon, and shine with such lustre as even in tropical countries to be visible in bright day; their apparent diameter, however, is no doubt greatly overestimated. Some of the most remarkable of these fiery globes were observed on March 31, 1686, in Italy and Germany; July 9, 1686, in Saxony, visible for seven minutes; March 19, 1719, in England, in brightness almost equal to the sun; December 11, 1741, in England, visible about one P.M., during a bright sun; November 26, 1758, in England, splitting asunder with a fearful noise; July 10, 1771, in France and England, where the ball must have been over 1000 feet in diameter; August 18, 1783, in England, France, and the Netherlands,

about fifteen miles high, and 2500 feet in diameter; March 8, 1798, in Switzerland; October 23, 1805; &c. With respect to the one seen on the Main, June 4 and 5, 1737, its least distance from the earth was estimated at thirty-four miles, and its velocity at somewhat more than that of the earth. There is no year in which fire balls are not observed in some place or other. Among those from which masses of iron fell are to be reckoned the meteors of May 26, 1751, near Agram; December 14, 1807, in North America, of 500 feet in diameter; June 15, 1821, in France, about three P.M.; &c.

The preceding remarks will suggest a connexion as existing between the fire balls and the *meteoric stones*, or *aerolites*, as we call those stones and mineral matters which fall after the splitting of the former. Aerolites do not, however, always fall from fire balls; sometimes they are cast from a small dark cloud, which suddenly forms in a clear sky, with a noise resembling that of single discharges of cannon. In much rarer instances the sky was clear, and there was no noise. Since the time of Chladni scientific men have been convinced of the quite frequent occurrence of falls of stones of greater or less dimensions from the atmosphere; the earlier accounts of this nature were generally considered as fabulous. On the 16th of June, 1794, a shower of stones occurred at Sienna; on the 13th of December, 1795, a stone fell in England weighing fifty-six pounds; on December 13th, 1798, several stones fell from a great fire ball; and on the 26th of April, 1803, a great shower of stones occurred near Aigle in France, which was verified and investigated by Biot. In France ten such falls were observed in twenty-six years (1790 to 1815), from which it has been calculated that on an average 700 take place in the year, over the whole surface of the earth, or nearly two daily. In 1803 there fell at Aigle about 2000 fragments of stones, weighing from two drachms to seventeen and a half pounds each, over a surface of two and a half French miles in length, and one mile in breadth; the masses examined immediately after their fall were hot, some still glowing, and many exhibited traces of impression or indentation. The depth to which these stones bury themselves in the earth is very various; the greatest known is that of the mass weighing seventy-one pounds, which fell at Agram on the 26th of May, 1751; its diameter amounted to eighteen feet.

The shape of meteoric stones varies very much, in general it appears to be based on that of an inequilateral three or four-sided prism, or a distorted pyramid. The surfaces of the stones are rarely smooth, generally curved in such a manner that the convexity of one side corresponds to the concavity of the other; larger or smaller indentations are frequently seen on the outside. A characteristic of all meteoric stones is a peculiar thin, black rind, sometimes over a quarter of a line thick; they are occasionally of a pitchy lustre, and sometimes veined, frequently soft at first, discolored, or dusty.

The internal structure of different meteoric stones exhibits some general resemblances, and at the same time great differences. Some are very porous, absorbing water very readily; others are very compact. The

specific gravity varies from 1.94 to 4.28, being at a mean about 3.5. Some masses contain not less than .96 of pure metallic iron, with a little nickel; of this character was the mass weighing 1400 pounds, found in Siberia in 1749, as also the Mexican specimen found at Zacatecas or Durango, weighing from 30,000 to 40,000 pounds, and other masses in all probability of meteoric origin. (The largest known aerolites, next to the Mexican just mentioned, are, one found in Bahia, and one near Otumpo in the province of Chaco, each from seven to seven and a half feet long, and weighing, the former 30,000 pounds, the latter 14,000 pounds.) Other aerolites again contain but two per cent. of iron, and some no metallic iron at all. We may therefore divide them into two classes: nickeliferous meteoric iron, and meteoric stones, properly so called. The metallic iron interspersed in almost all gives them a peculiar character; as for the rest, we find in meteoric masses the same chemical elements that occur in the earth's crust, namely, eight metals: iron, nickel, cobalt, manganese, chromium, copper, arsenic, and tin; five earths: also potash, soda, sulphur, phosphorus, and carbon; in all eighteen, or about one third of the known elementary bodies.

With respect to the actual nature and origin of all these phenomena, the majority of investigators agree with Chladni that they are of cosmical, not atmospherical origin, being in all probability small masses, *asteroids*, moving with planetary velocity, and revolving in space about the sun in elliptic or parabolic orbits. Should they come within the sphere of the earth's attraction, they are drawn off their course, becoming luminous on entering our atmosphere. The earth's attraction need not necessarily destroy the motion of all these bodies coming within its sphere; the only effect may be an alteration in the orbitual motion of the body around the sun. We may assume the existence of several meteoric currents, composed of innumerable small worlds following each other in a closed ring; the different currents probably intersect the orbit of our earth like Biela's comet, and the earth must, among others, pass through two of these currents in August and November. These asteroids are in all probability distributed very unequally in these closed rings, so that there may be only a few crowded groups; such a supposition may explain the rarity of the more conspicuous phenomena of this character. It is, to be sure, very enigmatical that the meteoric masses commence to shine and to become inflamed at heights which are considered as destitute of air. It is also a question, among many others which we cannot answer, whether the particles which compose the dense mass of a meteoric stone are originally distinct from each other in a gaseous condition, and first commence to be drawn together at the time they begin to shine; also, whether from the small shooting stars a compact mass may fall, or only a meteoric dust. A hypothesis, broached as early as 1660, suggests that meteoric stones may come from the moon, being ejected from volcanoes in active operation, a supposition readily refuted by the fact, as far as known, of the entire absence of active volcanoes on the moon. The older hypotheses of a telluric or atmospheric origin of meteoric masses are equally untenable.

8. *Of the Electric Phenomena of the Atmosphere.*

Very soon after the discovery of electricity, attention was called to the remarkable similarity of its effects to those of lightning, particularly by Gilbert, Grey, Nollet, and Winkler. It was reserved for Benjamin Franklin to insist more fully on this identity, and to indicate the experiments by which this was to be proved, experiments performed nearly simultaneously by himself and others in France and England in 1752. Franklin made use of a paper kite with a hempen string, which he held in the hand. This apparent child's play is for certain occasions, as when with a moderate wind it is wished to investigate the electricity of the higher strata, even yet the simplest and most applicable method. A great advantage is found in combining several kites into one system; nevertheless, in a highly excited atmosphere, this experiment becomes very dangerous. Other experimenters employed pointed iron rods, supported by insulating glass posts, and either standing freely in the air or else attached to some high building; this arrangement, however, is only calculated for intense electricity, as the glass posts soon lose their insulating property, owing to their becoming coated with dust or rain. An electrometer is used to measure the intensity of the fluid. Saussure armed the upper end of his electrometer with a wire two feet in length: it is still more advantageous to apply a flame to its point (or to attach a piece of burning sponge). A very useful piece of apparatus is a small Leyden jar of about ten or twelve square inches of inner coating, the conductor consisting of a metallic point projecting two inches above the jar, on which a metallic wire, of about three feet in length, with spiral turns, is attached, and often capable of being removed after charging the jar.

Traces of electricity are almost always found in the atmosphere, especially in clear weather: during a cloudless sky this electricity is always positive. The intensity of electricity in the same place is very variable, and subject to a regular oscillation. Feeble at sunrise, it increases until six and seven A.M. in summer, eight and nine in autumn and spring, and ten and eleven in winter. It then again decreases, reaching its minimum in summer about three, and in winter between four and six P.M.; at sunset it again commences to ascend, reaching a second maximum about one and a half or two hours after. This intensity likewise varies with the season, being greatest in the lower strata in January, and least in May, at the time when the air is driest. There is the most intimate connexion, as shown by Schübler, between the daily and yearly periods of electricity and the variations of relative moisture. The intensity of positive electricity is also greater with the distance from the surface of the earth, as is shown by even slight differences in height. The intensity of electricity is remarkably great during the deposit of dew, and in fogs; also when after long continued bad weather it clears up suddenly, or when clouds have quickly formed and do not immediately separate. We sometimes find negative electricity in clouds and fogs, but only when rain has fallen from them. All water deposited from the air is more or less electric, the electricity being sometimes positive,

sometimes negative; more frequently the latter. The intensity also is in proportion to the amount of condensation and the water falling in a given time. The direction of the wind is also of great influence: in north winds the rains are most frequently positively, and in south winds negatively electrified. In positive deposits the electricity is generally more intense than in negative, this electricity being usually far greater in amount in summer than in winter.

The most magnificent and at the same time most complex exhibition of electricity is furnished by *thunder* and *lightning*. Thunder clouds are generally small at first, but increase very rapidly, and soon cover the previously clear blue sky. Their color is in some places dark grey; under certain circumstances, however, exhibiting brilliant colors, particularly when, situated in a western sky, a declining sun tinges them with a yellow passing gradually into grey or blue. Generally a slow continuous falling of the barometer is observed previous to the formation of the cloud, accompanied in summer by an oppressive sultriness and a calm condition of the atmosphere. Should a thunder-cloud have formed in the vicinity of the zenith, a brisk wind rises at its approach, which blows in every direction from the cloud: in the cloud itself motions more or less lively are exhibited, and the electricity of the atmosphere quickly increases. The height of thunder clouds is sometimes very great, amounting occasionally to more than 20,000 feet. Should the charge of electricity in the cloud be sufficiently heavy, a flash of lightning will take place. Arago distinguished three kinds of lightning: 1. That consisting of a very fine and well defined luminous line, generally serpentine or zigzag. 2. That which illumines a great surface of the heavens at once; sometimes, however, only the outlines of those clouds from which it comes. 3. Lightning of greater duration than several seconds, of a well defined, generally spherical form; in this respect similar to the fire balls already described. The most frequent lightning is that of the second class. The color of lightning is sometimes white, sometimes bluish, violet, or red. A very deep red frequently characterizes lightning of the second class, whose light at any rate is generally less white and lively than that of the first. The duration of lightning of the first or second class is exceedingly short, not amounting even in the most brilliant and extended flashes to the thousandth part of a second. A division of a zigzag flash of lightning into two branches, very rarely into three, is some times observed. In many cases the discharge takes place between different strata of cloud, in others between a cloud and the surface of the earth: as a general rule, the flash comes from the cloud to the earth; sometimes, however, it passes from the earth to the cloud.

A noise of greater or less intensity, called *thunder*, generally accompanies the lightning. It differs greatly in its duration and character at different times, and appears to be much modified by the echo of terrestrial objects, and especially of mountains. When lightning strikes in our immediate vicinity, we hear first a sharp crack, and then a rattling sound in the distance. In other cases, particularly when the discharge takes place between the clouds themselves, there is heard a dull rolling or rumbling,

sometimes lasting for several seconds, and occasionally swelling out and becoming stronger, and again fainter. In single cases the duration of the sound has been estimated at from half to three quarters of a minute. The longer duration of the thunder is explained by the time necessary for the effect of the lightning in the air to come to the ear, the path of the lightning often being of great length. There is generally a certain interval between the flash of lightning and the breaking forth of the thunder; this is because sound requires a longer time to traverse a given space than light, and in this way we may calculate the distance at which a visible discharge of lightning took place, by noting the time which elapses between the flash and the report. Allowing in round numbers 1000 feet for every second, the interval in some cases is less than half a second, in others forty to fifty, and in an instance cited by Arago seventy-two seconds.

Lightning without thunder often occurs in nearly clear as well as in cloudy weather. This *heat lightning* is seen in the horizon in low distant clouds, whose distance is too great to hear the accompanying thunder. The lightning seen at a little distance above the horizon shortly after sunset in a clear sky, appears not always to be accompanied by an explosion of thunder, but is at any rate an electrical phenomenon.

Lightning always follows the best conductors in its passage to the earth, and especially metals, in whatever way these may be covered by other bodies. As a general rule, little injury is produced, except on entering and leaving the mass, in which case the surrounding bodies are thrown about, torn up, pulverized, &c., the metal itself being partially melted. This is strikingly the case with wires which are not thick enough to allow of a ready passage to the fluid. Besides metals, lightning strikes men and animals, which are either killed or rendered senseless: these, next to metals, appear to be the best conductors, and after them, moist objects in general. Elevated bodies, particularly if they happen to be good conductors, are most apt to be struck, as towers, trees, steeples, &c. Sometimes what are called *magic circles* are seen in meadows, circles of three or four feet in diameter, where the grass has been singed. This appears to be owing to the lightning having fallen in considerable quantity. The second crop of grass from these circles is generally much fresher and greener than the rest of the meadow. When bad conductors are interposed in the path of the electric discharge, they are torn in pieces and scattered around, exercising not unfrequently an enormous power. Thus, in England, in the year 1809, a wall consisting of 7000 bricks, and weighing about twenty-five tons, was displaced from its position. In many cases part of the effect produced is to be ascribed to the sudden formation of highly elastic steam from the moisture of the conductor. We thus explain the fact that the green living tree, containing an abundant supply of sap, is more injured than a dead one, in which only a small portion of moisture exists. When combustible bodies are struck, they are generally set on fire; sometimes, however, only carbonized or shattered, in which latter case we sometimes speak of a *cold stroke*. The stroke is generally accompanied by a peculiar smell, due probably to the sudden formation of ozone.

Whether the lightning actually penetrates into the body of the earth on striking, or whether it merely becomes diffused over the surface, depends in every instance upon the peculiarities and conducting power of the surface, and upon the bodies subjacent. Such bodies are oftentimes considerably affected, becoming melted, glazed, or otherwise altered. When lightning strikes loose sand, it frequently marks its passage by the formation of long tubes composed of the melted sand (known as *lightning tubes* or *fulgurites*), which are found in various regions of the earth. They generally present the appearance of a tube of unequal diameter in different parts, contracted inferiorly, and then running out into a point. The outer surface is generally rough and sandy; the inside, however, well fused and smooth, and of a greenish color. The length amounts to from twenty to thirty-five feet, with lateral branches of from an inch to one foot; the diameter from three quarters to twenty French lines; and the thickness of the walls from one quarter to eleven lines. All these tubes that have been followed to any distance appear to lead to water. Even on the surface of hard rocks a glazing is sometimes noticed, probably produced by lightning.

One striking effect of lightning consists in its affecting those magnetic needles in whose vicinity it passes, sometimes reversing the poles, and even altogether destroying their magnetism. Under the same circumstances magnetism may be communicated in greater or less intensity to unmagnetized bars of iron or steel. These phenomena only confirm the belief in the electrical character of lightning.

A curious action of atmospheric electricity, to which attention has recently been called by Professor Joseph Henry, is the effect produced upon the magnetic telegraph. Not only are the wires often struck by direct flashes of lightning, and destroyed or injured, but an inductive influence is exerted by distant clouds, which sometimes causes an almost fearful play of the register. In many instances thunder storms have recorded their own approach on the fillet of paper long before there was any other evidence of the fact. And, indeed, in some cases the same effect has been produced without the agency of electrified clouds, but simply by the different electrical conditions of the strata of air through which the wires pass.

Besides the direct stroke of a lightning discharge, we also have the *returning stroke*, by which all the terrible effects of lightning may be produced at a considerable distance from the place where the preceding direct discharge had taken place. This phenomenon is explicable on the theory of electrical induction. The simplest case is that in which a large and heavily charged cloud electrified the earth by induction; on the discharge of the former the latter again is restored to equilibrium by the diffusion of the electricity which had been heaped up, this diffusion, when taking place through bad conductors, producing all the mechanical effects of ordinary lightning. The returning stroke is on the whole less dangerous than the other, and no credible instance has been adduced of its inflaming bodies.

Of all parts of the earth, thunders and lightnings are most abundant in the

torrid zone during the rainy season (especially at the beginning and end). They here succeed each other almost daily at the times of maximum heat, while the lightning appears to be sharper as well as more luminous than in more temperate regions. With respect to the annual distribution of thunder and lightning in higher latitudes, the comparisons of Kaemtz show that thunder storms occur on an average about nineteen or twenty times each year in France, Holland, and Germany. Of these most take place in summer, the relative proportion in Germany being sixty-six per cent. in summer, twenty-four and a half in spring, eight in autumn, and one and a half in winter. In Russia and other interior portions of the old world, winter thunder storms are entirely wanting; there are seventy-nine per cent. in summer, sixteen in spring, and five in autumn; the total number appears to be less than in Germany and France. In Scandinavia the number of thunder storms is still less, continually decreasing towards the north. In the highest northern regions whole years elapse without thunder being once heard. On the west coast of Norway, particularly in the bishopric of Bergen, where about six thunder storms occur in the year, the winter storms predominate, these on the other hand being entirely wanting in Sweden. In Iceland, also, and on the western coast of North America, the winter thunders are most numerous; the Faroes, the Hebrides, and the Shetland Islands, not being entirely free from them. In Germany summer and winter thunders are distinguished by the greater poverty of lightning in the latter, and in frequently accompanying regular storms, while the former almost always arise in calm weather. Thunder and lightning are especially prevalent in mountainous regions, where a peculiar phenomenon is presented in this respect, namely, that a mountain crest or peak often forms a dividing line, beyond which such weather does not pass. Wooded mountains seem better adapted than bald for this purpose. It is especially the case, where a valley divides into several branches, a steep mountain standing in the forks of division, that storms coming up the valley often tarry about the mountain, and subsequently divide.

On Lightning Rods.

A *lightning rod* is a contrivance invented by Franklin for conducting a stroke of lightning over or along a building or object of any kind, without any of the terrible effects of this powerful agent being exhibited. As lightning always follows the best conductor, it is very reasonable to suppose that a continuous rod of metal, of sufficient thickness, would carry it over a certain space without producing any injury to the poorer conductors in the immediate vicinity. Another suggestion of Franklin, that the electricity of a cloud may be silently drawn off by a pointed conductor, and a stroke thus averted, met with a great many opponents. It has been especially objected that the points of lightning rods, from their small extent and surface, must be incapable of carrying off a powerful discharge without injury; in fact, it has not rarely been found that they have actually been melted, and even the

replacing the points by a better conducting metal, as copper or brass, cannot always avert this result.

The various arrangements employed for lightning rods may be divided into three classes: 1. Conductors of metal strips; 2. Conductors of metallic wire; and 3. Conductors of iron rods. Furthermore, we distinguish in each conductor three principal portions: the highest part where the lightning discharge is received; the middle part; and the inferior portion, or the end. Reimarus advises to carry a continuous metallic strip along the comb and eaves of the roof, across the gable ends, up the chimneys, and down the corners of the house. For this purpose, sheet lead of the proper thickness is very well adapted. In this case a special pointed conductor is not necessary. Reimarus recommends its use only in the case of thatched roofs. Should rods be deemed necessary, they must, according to him, be erected at the most exposed places, especially the chimneys and gables, to a height of about four feet, without points, and of at least three quarters of an inch in thickness. The communication between the strips of lead just mentioned and the ground, may best be established by means of copper or lead strips, about three inches wide, nailed to wood. To prevent the oxydation of the metal, it should be covered with a good coat of oil paint. It is unnecessary to separate the conductor from the building by iron or wooden pins or clamps. It is not advisable to inclose the conductor in the masonry or other inner portion of the building. The lower end of the conductor should, if possible, dip into open, and, indeed, running water, to assist in the diffusion of the electricity. When the extremity of the conductor leads into a covered channel of water, the inflammable gas which sometimes is present may be set on fire by the lightning, thus producing an explosion. It is advisable to have the conductor end in several branches, to multiply the points of egress. The conductors of vessels are best constructed of thin brass chain, or still better, of copper, linked together in joints of about six or eight inches long.

Saussure recommended conductors of brass wire. They have been extensively employed in Bavaria, without presenting any very pre-eminent advantages. Conductors of iron rods are not only the longest known, but also the most generally used. The Academy of Sciences at Paris, together with most French philosophers, recommend them above all others.

Professor Henry has suggested a very simple and effectual method of protecting a house, without much expense. It consists in employing the spouting as part of the conductor, by having the projecting rod connected with the gutter above, and leading a thick wire or iron rod from the lower end of each spout to running water or other good conductor. As most houses have a system of gutters along all the eaves, connected with the ground by several spouts, it would seem that this is an excellent, safe, and economical plan.

According to Pouillet, every lightning rod must consist of two essential portions, a pointed metallic rod projecting in the air, and a good conductor connecting the rod with the ground. To be of the greatest efficacy, the rod must terminate in a very fine point. The connexion with the ground must

be perfectly conducting, no interruption of continuity taking place between the point and the ground; and all parts of the apparatus must be of the proper dimensions. The great advantage of a point consists, according to Pouillet, in this: that when a thunder cloud passes over the rod and decomposes its combined electricity by induction, by repelling the like and attracting the like kind, the latter can stream out into the air from the point. In this way no accumulation of electricity in the rod can take place, and no danger will be experienced in approaching it, or even from coming into actual contact.

Pl. 27, *figs.* 14—19, represent a lightning rod as recommended by Gay Lussac. This rod is about twenty-seven or twenty-eight feet long, and consists of three pieces, an iron rod $25\frac{3}{4}$ feet long, a brass piece of two feet, and a platinum needle of from one to two inches in length, together forming a cone tapering gradually above (*fig.* 15). The brass rod is screwed into the iron rod and secured by pins. The platinum needle is soldered to the brass rod by silver solder, and the joint surrounded by a copper nut, as in *fig.* 16. The iron rod consists sometimes, for more easy transportation, of two or more pieces screwed into one another and fastened by pins. *Fig.* 14 represents three different modes of attaching the rod to a building. Under the rod, about two or three inches from the roof, a plate, *bb'* (*fig.* 17), is screwed to carry off the water; one or two inches above this plate the rod must be cylindrical and well turned, in order that a hinged ring, *ll'* (*figs.* 17 and 18), may be applied, to which the conducting rod can be attached. This latter is a quadrangular iron rod of seven to nine lines in thickness, screwed to the ring *ll'*, and carried over the roof, and along the house to the ground. Here it should terminate in several branches and windings, dipping into a constant current of water, or into a hole bored to a depth at which water exists, and filled up with powdered charcoal. Should there be no water in any way accessible, the rod should at least be carried through a channel filled with charcoal to a damp place. Instead of the conducting rod we may use a rope of twisted copper wire (*fig.* 19). A well-constructed rod of the dimensions just given, will protect a space of about sixty feet radius; and generally, a projecting rod will protect an area whose radius is twice the height of the rod. Should the rod project from the roof of a house, we must estimate the amount of protection extended to the house by the elevation of the rod above the roof.

The straw-rope hail and lightning conductor of La Postolle, pronounced perfectly useless on its first announcement, by the French Academy, has been already mentioned under the subject of *Hail.*

The inefficiency of all the earlier protective means, as the burning of great fires, the firing of cannon, &c., is now universally recognised. The ringing of bells, customary during thunder storms in olden times, and still practised in the Tyrol, is not only useless but dangerous to the persons concerned, who thus complete the electric communication between the bell, through the rope, and the earth. It has been estimated that in the short space of thirty-three years, not less than 386 church steeples have been struck, and 121 persons engaged in ringing the bells killed.

It still remains to mention an occasional electric phenomenon known at the present day as *St. Elmo's Fire* (and to the ancients as *Helena*, or *Castor* and *Pollux*). During the disturbed condition of atmospheric electricity in storms, and at other times, flames are observed on elevated objects, such as metal points of towers, mast heads, &c., which are sometimes heard to crackle along these objects, but without doing any injury. This is nothing more than electrical light streaming forth during a great accumulation of free fluid, and is especially observed during violent storms, as also in snow and hail squalls. The ancients, when they saw two of these lights (Castor and Pollux) on the tops of the masts, considered them as indicative of fair weather, while a single one (Helena) was supposed to portend a storm. This phenomenon is presented more frequently in winter than in summer, and is sometimes exhibited in the former by a luminosity of the snow flakes, in the latter by the same peculiarity in the descending rain or hail. When the amount of free electricity is very great, it is seen on low objects, stalks of grass for instance, as observed by Burchell in South Africa; also on lance heads, canes, finger tips, ears and manes of horses, &c. The balls of fire sometimes observed, as distinguished from the flames or stars, may be the exhibition of negative electricity, the latter being positive.

9. *Of Terrestrial Magnetism.*

The influence exerted by terrestrial magnetism, at any locality on the earth, is determined by measuring the magnetic declination, inclination, and intensity, as its three exponents. For the general consideration of this subject we would refer our readers to what is said on page 141. To determine the declination and its variations, the method of Gauss, and the accompanying apparatus, the *magnetometer*, are almost universally used. In this instrument, instead of small magnetic needles, magnetic bars of from five to twenty-five pounds' weight are employed. A bar of this character, eighteen to thirty-six inches long, three to six lines thick, and fifteen to twenty-four lines broad, is placed on a nut of brass, which is suspended from the ceiling of a room by a fine wire, or thread of untwisted silk, about seven feet in length. A plane mirror is fastened to one end of the bar, whose plane stands perpendicular to the magnetic axis of the bar: opposite to the mirror, but at a distance of about sixteen feet, a telescope is attached, whose optical axis inclined slightly downwards is directed immediately towards the centre of the mirror. The angle made by the optical axis of the telescope with the plane of the astronomical meridian must be determined with the greatest possible accuracy. A horizontal scale about four feet long, graduated to millimetres, is attached to the stand of the telescope, perpendicularly to the direction of the magnetic meridian, and at such a height that the image of a part of it is seen by reflection in the mirror. A thread stretched by a weight, and in contact with the scale, hangs before the middle of the objective indicating the middle or zero point of the scale, that is, the point which lies in one and the same plane with the optical axis of

the telescope. As security against currents of air, the bar hangs in a box having a small aperture in its movable cover to allow the passage of the thread, and another hole in the side opposite to the telescope for the mirror towards which the former is directed. Should the magnetic axis of the bar fall in the same vertical plane with the optical axis of the telescope, the image of the zero point of the scale will fall accurately in the axis or the cross-hair of the telescope; if this be not the case, the image of some other point of the scale than the zero point will appear in the latter, and when the distance of the scale from the mirror is accurately determined, we can readily calculate from the observed parts of the scale, the corresponding angle made by the magnetic axis of the bar with the optical axis of the telescope, and from the latter the corresponding declination. Neither the inclination nor the intensity can be ascertained with the same exactness. See page 144 for the determination of the intensity.

Magnetic Observatories have been erected in various parts of the earth since 1828, thanks to the ceaseless efforts of Humboldt, observatories in which uninterrupted hourly observations are made for twenty-four or thirty-six hours in succession, at certain epochs. One of the most complete and best arranged establishments of the kind is the one in Greenwich, adapted also for making and registering meteorological observations. *Pl.* 27, *fig.* 20, represents this in ground plan, while *fig.* 21 presents a general view of the building as seen from the north. On the north side, a mast is erected to a height of eighty feet, intended for electrical observations. On the right side of the drawing a ball is seen on the ground, which, with its lantern, is intended for induction observations, and may readily be drawn to the top of the mast. The small building to the left is intended for observations on the magnetic inclination. The box not far from the door of the main building contains various thermometers, and may be turned so as to keep constantly in the shade. The main building itself, built of wood exclusively, without iron, and fourteen feet high, forms a cross of four equal arms or wings, which are erected according to the magnetic meridian, and, in the clear, are twelve feet broad and ten feet high. The distance between the extremities of two opposite wings within the walls amounts to forty feet. The northern wing is separated from the middle space by a wall, thus forming a kind of antechamber. The letters of the plan indicate as follows: *a* the declination magnet in the southern wing, *b* the horizontal magnet in the eastern wing, *c* the vertical magnet in the western wing, *d*, *e*, *f*, three telescopes for observing the three magnets, *a*, *b*, *c*, from a single point (chair), *o*; *g* is the scale of *b*, *h* that of the vertical magnet, *i* a clock keeping mean time, *l* an astronomical clock, *m* a clock in the antechamber, *k* a barometer, *n* a chimney, *p* an alarm door bell, *q* a shed or offset for the electrical apparatus, *r* an opening in the roof in the direction of the astronomical meridian.

The *declination magnet* (*pl.* 27, *fig.* 24) is a thick magnetic bar of hardened steel, two feet long, one inch and a half broad, and one quarter of an inch thick; *b* is a brass ring with two plane glasses, between which are cross-hairs of spider's web; *d* is the lower part of the attachment apparatus;

e is a silk thread to which the magnet is suspended. This thread rises eight feet nine inches high, passes over two pulleys, *f* and *g*, and is attached by a piece of leather to the small reel, *h*, which, by the aid of a catch, permits the magnet to be elevated or lowered ; *i* is a copper hoop, serving to restrain the oscillations of the magnet. The whole apparatus is placed on a metal stand, which rests on a particularly firm foundation. On the cross-arms is a rectangular box, coated inside and out with gold paper, in which the magnet swings freely.

The horizontal magnet is represented from the south-west in *fig.* 23. Here *a* is the magnet, *b* the mirror attached, *c* the circle of rotation, *d* five pairs of small pulleys, *e*, *e*, two silk suspension threads passing from the uppermost pair of pulleys to two pulleys, *f*, placed seven feet nine inches higher ; thence they proceed over the pulley *g*, and finally to a larger pulley not shown in the figure. A catch wheel is attached to this latter pulley, its winch being shown at *h*. The magnet is similar in dimensions to the one already described, with a similar stand, eleven feet five inches high, and is surrounded by a copper hoop, *i*. Like the preceding it swings in a double box, whose south side consists partly of plate glass. A scale is attached to the wall of the eastern wing, about eight feet five inches south of the magnet, and is sighted by a telescope directed to the mirror, *b*, of the magnet. The magnet is placed in a direction perpendicular to the magnetic meridian, being held there by the tension of the threads, *e*, *e*. It strives continually to place itself in the direction of the magnetic meridian, turning the two threads, sometimes with greater, sometimes with less force, so that in consequence of the reflection from the mirror *b*, different numbers on the scale are constantly appearing.

The vertical magnet is seen in *fig.* 22. Here *a* is the magnet, *b* the mirror with adjusting screw placed on it, *c* a knife edge on which the bar turns, *d* one of the two agate plates on which *c* rests, *e*, *e*, screws by which the centre of gravity of the magnet and its inclination may be altered, *f* the bronze support on which the magnet rests. The latter is of like dimensions with the preceding, and is placed on a similar stand.

Pl. 27, *fig.* 25, exhibits the electrical apparatus placed in the window of the antechamber. In this, *a* is the hook which effects the connexion of the conducting wire with the apparatus, *b* is a screen covering the opening in the window, and through which there passes a vertical rod sustaining the apparatus, *cc* is a double truncated glass cone, fastened to the upper glass frame on each side by beds of brass, *d*, *d*, are lamps for keeping this glass cone constantly dry, *e* is a nut inclosing the glass cone, and carrying the hollow copper cylinder, *gg*, by means of the vertical arm, *f*. From this cylinder there pass out eight lateral arms, in which conducting rods can be moved freely up and down, and fixed at any part by screws. At *h* there is seen a *Bohnenberger* gold leaf electrometer, *i* is a galvanometer for determining the electric currents in the atmosphere, *k* is an instrument for measuring the length of the electric spark, *l* is a second dry pile apparatus, similar to *h*, but less sensitive, *mm* straw electrometers for determining electric changes in the atmosphere.

Finally, *fig.* 26 represents the electrical light apparatus, and in fact exhibits the apex of the electrometer. *a* is a lantern at the upper end, whose lamp burns constantly, *b* is a copper tube on which the lantern slides, fastened to the glass cone, *c;* this latter is hollowed beneath and coated with copper, under which stands the lamp marked *e*, constantly burning to heat the copper, and thus to maintain the glass cone in a proper condition of dryness; *d* is a wooden apparatus receiving the lower part of the cone, *f* is a conducting wire leading to the electrical apparatus in the antechamber, *g*, *g* are iron wires, by means of which the whole apparatus may be moved up and down.

The different values of the observed magnetic declination, inclination, and intensity, in different parts of the earth, are represented on charts by three systems of lines, called after Humboldt, *isogonic*, *isoclinic*, and *isodynamic*. *Isogonic* lines connect those parts of the earth possessing equal declinations. Charts on which they are delineated are called *declination maps;* they can, however, be relied on as accurate for a short time only, as the magnetic declination of a place is constantly changing. Nevertheless there are places on the earth where the declination does not sensibly change for a considerable period of time; among these are Spitzbergen and the western part of the Antilles. Among all the isogonic lines the line of no deviation is most remarkable, the line connecting all places where the needle points due north, or where the magnetic and astronomical meridians coincide. This passed through London in 1657, and through Paris in 1669. It divides the earth into two portions, of which the one has an eastern and the other a western deviation of the needle. The latter portion embraces all Europe, excepting a small part of Russia, Africa, and nearly all of the Atlantic Ocean. In north-eastern Asia the isogonic lines form a closed system of oval outline, this same condition being represented more regularly and of greater extent in the South Sea, between 20° N. and 45° S. latitude. In the Asiatic oval the deviation increases from without to within, while in that of the South Sea the reverse occurs. The chart occupying the middle of *pl.* 28 represents the observed values of the declination in the years 1827–30, in isogonic lines after Adolphe Erman. The figures accompanying the lines indicate the degree of declination, the western being taken as positive, the eastern as negative.

Isoclinic lines connect those parts of the earth possessing the same magnetic inclination, and are represented on *inclination charts*. That one of these lines connecting those places where the needle is horizontal or has no inclination, is called the magnetic equator; to the north of this the north end of the needle will dip towards the earth, the reverse taking place to its south. In 1825 the one point of intersection of the magnetic and terrestrial equators was situated near the Island of St. Thomas, in the western coast of Africa, and distant 188½° from the node in the South Sea; from 1825 to 1837 the former node has moved 4° towards the west. On the coast of Brazil the magnetic equator is 15° south of the terrestrial. A great advantage in investigating and establishing the laws of terrestrial magnetism is found in the fact, that all but about one fifth of the magnetic equator falls

in the ocean, and is therefore readily accessible. Those places on the earth where the dipping needle stands vertically are called the magnetic poles; of these there are two, one in the southern and one in the northern hemisphere. They are also characterized by the fact, that in all regions near one of these poles the horizontal needle is directed immediately towards it. *Pl.* 28, *figs.* 1^a and 1^b, represent the isoclinic lines of the northern and southern hemisphere for the year 1825, after the chart of Admiral Duperrey, who crossed the magnetic equator six times between 1822 and 1825.

Isodynamic lines connect those places which possess the same intensity of magnetism. *Fig.* 2 exhibits these lines for two hemispheres, likewise after Admiral Duperrey. In general the magnetic intensity increases from the terrestrial equator to either pole, but the isodynamic lines run parallel neither with the magnetic nor the terrestrial equator. An arbitrary unit has been made of the intensity observed at the magnetic equator in Peru by Humboldt, although this is by no means the minimum of observed intensity: this real minimum amounts to seven tenths of that assumed as the standard, and occurs on the coast of Brazil. By connecting those places in each meridian in which the intensity attains its minimum, we shall have a line, called by Duperrey the magnetic equator, which, however, by no means appears to coincide with the aclinic line, or line of no inclination. The maximum of known intensity amounts to a little over two, and occurs near the south magnetic pole; the observed maximum is thus about twice the minimum. Near the magnetic north pole in Melville Island it only amounts to 1.6. (See *pl.* 28, *figs.* 1^a and 1^b, where the term "magnetischer (magnetic) equator," is to be taken in the meaning of Admiral Duperrey.)

The oscillations of the magnetic needles depend much on the course of the sun, so that at one and the same place the time of day may be ascertained by the position of the needle. The hourly variations of declination increase in extent with the magnetic latitude or the distance from the magnetic equator; thus, in Middle Europe they amount to thirteen or fourteen minutes, and near the equator to but three or four minutes. In the whole northern hemisphere the north end of the needle appears on an average to move westwardly from $8\frac{1}{2}$ A.M. to $1\frac{1}{2}$ P.M., and eastwardly in the same interval in the southern hemisphere. It is quite probable that between the geographic and magnetic equators there is a region where no hourly variation of declination exists; this curve, however, has not yet been discovered. Sometimes there occur extraordinary disturbances or perturbations of the needle (*magnetic storms*), which are propagated in immeasurably short spaces of time in every direction over the earth's surface, being perceived at the same instant at the most distant stations. For this reason they may be employed in determining the geographic longitude.

The *aurora* exerts a greatly disturbing influence on the magnetic needle, for which reason this remarkable phenomenon is now almost universally considered as magnetic in its character, although no satisfactory explanation

of it has yet been suggested. In high latitudes it is far more frequent than in lower, occurring almost every night during certain seasons in the far north.

The aurora, mostly observed in winter, generally begins with a bright glow, at first white and then yellowish, in the northern part of the heavens; its shape is that of an arch inclosing a dark nebulous cloud, previously formed in the otherwise clear heavens, and appearing as a segment of a circle from eight to ten degrees in height, which does not obscure the stars. In the far north this segment appears brighter than with us, or is entirely wanting. The highest point of the arc generally deviates from five to eighteen degrees from the magnetic meridian, towards that side to which the magnetic declination of the place is directed. Sometimes there arise two or three bright arches. From one of these, generally the uppermost, there subsequently ascend streaks of light and groups of rays of different colors, alternately appearing and vanishing, and changing their place with greater or less rapidity, so that the entire mass of light appears to be in incessant motion, the whole heavens being sometimes filled with a flickering, tremulous light. The colors, in particular instances, pass from violet and bluish white through all shades into green and purplish red; black streaks, even, resembling a thick smoke, occasionally occur. These streaks of light sometimes ascend from the arch alone, sometimes simultaneously from many opposite points of the horizon. The rays at times converge towards that point of the heavens corresponding to the direction of the dipping needle, thus forming the so-called *crown* of the northern light (*pl.* 26, *fig.* 13), resembling the lantern of a dome, and only rarely coming to perfection, but always constituting the culminating point of the whole phenomenon. This soon after begins gradually to decrease, flames up a few times more, and then vanishes, leaving either a whitish gleam in the north, which lasts some time longer, or a light white cloud.

This phenomenon, mentioned by Aristotle and Pliny, was first called *aurora borealis* by Gassendi, in consequence of the one observed by him on the 12th of September, 1621. The fact that the aurora appears more frequently at certain times than at others, is well ascertained, without our being able to determine a regular periodical alternation. According to Mairan, the following is the rate of their occurrence in earlier times: 26 between 583 and 1354 A.D.; from 1446 to 1560, 34; from 1561 to 1592, 69; from 1593 to 1633, 70; from 1634 to 1684, 34; from 1685 to 1721, 219; from 1722 to 1745, 961; from 1746 to 1751, 28. From 1716 to about 1790 they were so frequent, that the Dutch philosopher, Muschenbroek, observed no less than 720 at Leyden and Utrecht; in Leyden 750 were observed in twenty-nine years, while in 1730, 116 in all were seen in different parts of the earth. After 1790 they became rarer, and it is only since about 1825 that they have been observed more frequently. The auroras of modern times, most conspicuous for their beauty, their wide distribution, and long duration, were those of the 7th of January, 1831, and 24th and 25th of October, 1847 (seen even in the southern latitudes of Italy and Spain). Mairan gives the following as periods during which no

northern lights appear to have been observed: from 1465 to 1520; from 1581 to 1600; and from 1721 to 1686. According to Bertholon, there were forty-nine years in the seventeenth century without any aurora. Hansteen indicates twenty-four aurora periods since 502 A.D., of which the ninth between 541 and 603, the twelfth between 823 and 887, the twenty-second between 1517 and 1588, and the twenty-fourth between 1707 and 1788, were eminently distinguished by the brilliance and frequency of the phenomenon. According to this author they are most numerous about the time of the equinoxes. Very few instances are on record in which they appeared by day, as on September 9th, 1827, in England.

The northern lights are sometimes visible in the torrid zone, and even in the southern hemisphere, just as the southern lights or *aurora australis* have been seen in the northern. In Europe, however, the northern lights do not appear often to descend below 37° of latitude. They are rarer in Switzerland, South France, and South Germany, than in Holland and North Germany. They are more numerous in Great Britain and Ireland, increasing to the sixty-fifth or sixty-sixth degree of latitude. Diminishing again in number towards the pole, their chief region appears to be in Europe, between 60° and 66° N. L. They are far more frequent in North America, and are visible further south than in Europe and Asia. The line of daily appearance of the aurora commences, according to Horner, at about 60° N. L., and 70° longitude west of Ferro, and runs thence north-easterly through Baffin's Bay, the point of Greenland, Iceland, and the northern part of Spitzbergen, attains its highest point at 60° east longitude, and then returns through the Siberian Arctic Ocean, and above Behring's Straits, to its starting point. The estimates of the height of the aurora are mostly very uncertain, varying between several miles and 3000 or 4000 feet. The distance from the earth is in all probability very different at different times, the phenomenon occurring not merely within the limits of the atmosphere, but even in the region of clouds. Some of the more recent observers even believe that the streamers of the northern light can be moved by winds and other aerial currents.

The connexion between the aurora and magnetism is not at all doubtful, considering the remarkable variations produced by the former in the magnetic declination, inclination, and intensity, especially since Faraday has discovered that light may be produced by magnetic forces. Even the morning previous to an aurora the irregular action of the needle indicates a disturbance in the equilibrium of terrestrial magnetism, and the needle is not seldom affected by the occurrence of this phenomenon in places where nothing of it is visible. It is only in the far north, beyond the actual zone of auroras, and near the magnetic pole, that there is no longer any influence of the northern light on the needle. These polar lights may then be considered as magnetic storms, during which the disturbed magnetic equilibrium is again restored.

In ancient times, and even up to the middle of the last century, the aurora was explained by supposing that terrestrial exhalations were collected in the higher regions of the atmosphere, and there inflamed.

Many philosophers considered it to be an optical phenomenon, produced by the reflection of solar light from the polar snow and ice, against the concave surface of the higher atmospheric strata, whence the rays were a second time reflected to the observer. According to De Mairan, it is produced by the coming of the earth at stated periods into the atmosphere of the sun, supposed to extend to the earth's orbit, an entirely false supposition, as shown by what is said of the dimensions of this atmosphere on page 237. According to Euler, it consists of solar rays, which, by their violent impact against the finer particles of the atmosphere, carry these to a height of more than 4000 miles, the height at which he believed them to exist. According to Kirwan, with whom Volta and Parrot agree, the northern light is produced by hydrogen gas generated by decomposition on the earth, volcanoes, and other causes, especially near the equator, and carried by aerial currents towards the polar regions, there to become inflamed. Before this, however, Halley considered it to be produced by the influence of magnetic currents from the two poles, and his hypothesis, in a somewhat modified form, is at present maintained by the most eminent investigators.

CHEMISTRY.

PLATES 30, 31.

Introduction.

IN her rise and progress *Chemistry* presents a remarkable page in the history of science. While no other field of human knowledge remained so long untilled, no other ever presented such glorious results of flower and fruit, after the first germ had taken root. The purely abstract sciences, philosophy, and especially mathematics, find their origin in a hoary antiquity, and their earliest teachings may serve as means wherewith to form the youthful mind of the present generation; they soon attained a rank among the true sciences, and what they taught has been but more firmly established by the lapse of ages. Not so with the natural sciences. It is not easy to assign the reason why the ancient naturalists, with all their acuteness, should have permitted their strivings after truth to be frustrated by an almost utter neglect of observation. Yet we cannot deny that efforts were made, with respect to many departments of science, to establish them on a firm basis. Aristotle divided the natural world into three great classes. His views of matter, however, as those of the other Grecian philosophers, could not stand a moment after chemistry became a science. Anaximander taught four elements as the primary constituents of our planet, fire, air, water, and earth; and centuries after no alteration was made in the doctrine, though the economical application of many substances, and the manipulation of many natural products, offered chemical facts which might have led the way to a scientific appreciation of chemical combinations and decompositions. The ancient Egyptians prepared many salts, as sal ammoniac, carbonate of soda, sulphate of iron, as also glass and tiles; they were able to reduce many metals from their ores, and to make various alloys. The embalming of dead bodies, the preparation of medicines, the fabrication of vinegar, beer, and other artificial products, as practised by the Egyptians, presuppose some chemical experience. The knowledge possessed by the Egyptians with respect to these and many other subjects, was diffused at a later period among the Jews and Greeks, and perhaps among the Chinese also. Yet, notwithstanding all this, we cannot go beyond the end of the seventeenth century, for the origin of scientific chemistry.

The manner in which chemistry at this time commenced her career is exceedingly remarkable. It was not the effort to elucidate certain obscure

ideas with respect to the combinations of matter, it was a delusion which occupied men's minds for many centuries in succession; and in futile endeavors to find the philosopher's stone and the elixir of life, a mass of facts was accumulated which served as material for the foundations of chemistry. From the seventh to the eleventh century the Arabians were principally engaged in the discovery and preparation of medicines. In a complete ignorance of the true character of the mineral kingdom, it is exceedingly likely that the problem of finding a substance which should heal all diseases, and transmute a base metal into a noble one, was suggested by the fact of their finding occasionally in the ashes of some worthless earth, or as the result of some chance experiment, a highly valued metal. The substance to which the above-mentioned virtues were ascribed was called the philosopher's stone, and the endeavor to find it caused, first of all, the Arabians to make a host of combinations of the most different substances. In this way they made many discoveries which were carried to Europe during the crusades, where the endeavor to transmute the common metals into gold was prosecuted with unprecedented ardor. From the thirteenth to the seventeenth century the art of making gold attained the rank of a so-called science, and while there were so many persons who actually did hope to solve the problem, this art, *alchemy*, gained the great consideration which it at that time enjoyed by means of deceivers, who knew how to conceal finely comminuted gold in substances, which, when mixed with lead, became visible for the first time, appearing as if an actual transmutation of the baser metal into gold had taken place. The writings of the alchemists were preserved as treasures, and they had at least the result of teaching a number of observations on the affinities of different substances, which, when properly understood, greatly facilitated the rapid progress of chemistry. The first chemical system arose with George Ernest Stahl, towards the beginning of the eighteenth century, a system which endeavored to arrange all known facts according to general principles; thus the development of chemistry falls within the limits of the preceding and the present century.

In its present form chemistry is the science of matter. It teaches the properties of matter, its mutual relations, and the laws of its combinations. These are ascertained in two ways: by combining several elements in a given manner, or by separating combinations into their elements, and measuring or weighing the ingredients. The latter method, or *analysis*, is by far more productive in results than the former, or *synthesis*. To recompose a substance from its elements, after these have been accurately ascertained, is a problem of great difficulty in many cases.

The number of simple substances contained in our earth is not very great, as we shall see hereafter, but the combinations of several single elements are numerous, while the secondary combinations with one another of these primary combinations of elements are vastly greater in amount, new ones being almost daily added in the progress of science. It is only necessary to point the observer to the various minerals, plants, and animals, of which each one possesses some peculiar odor, or color, or taste, or

product, or property, each involving some chemical difference, to give him some idea of how numerous the various combinations of elementary matter must be. The same consideration will also suggest how varied must be the experience to be collected by chemistry, and how diversified the experiments by which she ascertains her facts. With the progress of any science, the amount of its elucidatory and accessory apparatus increases, the latter being the true exponent of the former. In this view, a description of chemical apparatus, and of its application, will give us an idea of the present state of the great science of modern chemistry.

1. Conditions of Aggregation of Matter.

All ponderable matter, whether belonging to the mineral, to the vegetable, or to the animal kingdom, presents itself to us under one of three conditions of aggregation, depending on the temperature and pressure to which the body may be subjected. These states of matter are the solid, the liquid, and the gaseous.

The four elements of Anaximander, earth, water, air, fire, illustrate the difference between the idea of an element as entertained by the ancients and by the modern philosopher. The elements of the former, instead of expressing the elementary simple ingredients of which all bodies are composed, merely typified the three states of matter, earth answering to the solid, water to the liquid, and air to the gaseous. The fourth element, fire, may be considered as symbolizing the effects of the imponderable agents, heat, light, magnetism, and electricity.

We may safely assume that all solids are capable of being changed into liquids and gases, by the application of the proper agencies. It is well known that many of these solids are capable of this transformation, as seen in the conversion of the solid lump of ice, by the simple application of heat, into the liquid, water, and finally into the gas, steam. The fact, however, is not so generally appreciated that gold may be vaporized by the focal heat of a large mirror, and that the apparently infusible platinum, the metal which can withstand the furnace seven times heated, is speedily made to boil and disappear by the flame of the oxy-hydrogen blowpipe. We may therefore assume that all solids are capable of these transformations by the increase of heat and diminution of pressure. The converse is also most probably true, to the same extent, that all gaseous matter may be converted to solid by the diminution of heat and increase of pressure. In many cases, either heat or pressure, applied positively or negatively, may suffice; in others, both are required; and if they produce the desired effect neither singly nor in combination, we may analogically conclude that it is because of the inadequacy of our means, and not of the impossibility of the end.

1. *Apparatus for Melting Solid Bodies.*

Contrivances for melting solid bodies have the most extensive application in the arts. All workers in metal need them for producing the various forms or mixtures required. The daily operations of life involve them to a very great extent. Confining our attention to what is required for the more infusible substances, among which the metals are most conspicuous, we have, as most generally used, the *wind furnace* (*pl.* 30, *figs.* 3 and 7), and the *crucible furnace* (*figs.* 21 and 22). Thus, when a mixture of copper and zinc is required in making brass, pieces of both metals are introduced into a Hessian crucible (*figs.* 30–34), constructed of an exceedingly infusible clay. Charcoal powder is introduced into the crucible to prevent the loss of zinc, which arises from its ready combination with oxygen. The philosophy of the action of the carbon consists in its taking hold of the oxygen of the air entering the crucible, and being converted by it into carbonic acid. The zinc is thus protected from the influence of the oxygen, which would have been exhibited by the conversion of the metal into an oxyde by combustion; combustion or burning, in technical phrase, simply indicating a combination of oxygen with any inflammable base. The crucible is now set on the grate of the portable wind furnace (*fig.* 3), placed a few inches above the door *a*, and surrounded by red hot coals. The space above is then to be filled with fresh coal, and the door *b*, leading to the space below the grate, opened; the door *a* must be kept closed, its object being to allow an examination of the interior of the furnace with respect to the temperature, amount of fuel, &c. The funnel or cap, represented more fully in *fig.* 3*a*, is finally to be laid on the upper opening of the furnace As soon as the fuel has commenced to burn, a powerful draught of air draws through the furnace, owing to the heated air within being specifically lighter than that outside, and ascending continually through the cap, its place being supplied by fresh air entering at *b*. A great quantity of atmospheric air, consisting of seventy-nine parts of nitrogen and twenty-one of oxygen in the hundred, by volume, is thus introduced among the burning coals. The oxygen combining with the carbon with great avidity, produces an increase of heat, and the carbonic acid being immediately carried up and out through the funnel, permits a fresh accession of oxygen. The amount of heat generated will be in direct proportion to the amount of oxygen which has access to the carbon of the fuel, and to the rapidity with which the carbonic acid is removed.

When many operations of this kind are required it is customary, besides or instead of the portable furnace, to use one that is fixed, but similar in principle and action. A furnace of this character is shown in *pl.* 30, *fig.* 6; *fig.* 7 represents it in section. A is the space for the fuel, C the grate on which stands the crucible, supported by a block of crucible earth, as in *fig.* 21; B is the bottom of the ash-hole. The opening of A is closed by a well-fitting iron cover, which may be coated on the under side with clay. The draught in this furnace passes in at the ash-pit, through the fuel, and

out by a horizontal channel into the vertical chimney, D, which may be walled in the chimney of the building. By applying very high chimneys, a much greater draught can be obtained than with the preceding construction.

The *crucible furnace* (*pl.* 30, *fig.* 21) is still another arrangement, especially applicable when valuable metals, as gold and silver, are to be melted. The larger upper figure represents a small closed space, whose walls are formed of an infusible clay, and made in two pieces, the upper of which can be lifted off like a cover. The metal (or metals) to be melted is introduced into a crucible of plumbago, or into a Hessian crucible, and this placed on a block of infusible earth in the bottom of the furnace: burning coals are now to be placed round the crucible, and after replacing the top, the remaining space is filled with fresh coal. In the bottom of the furnace are six or eight channels, so arranged that the air forced by a pair of bellows into the space E, and thence through the channels, may be directed principally against the lower part of the crucible. The cover has a lateral aperture through which examinations may be made or fresh coal supplied. The crucible is removed after complete fusion of the metal has taken place. *Fig.* 23 represents a pair of tongs for handling the heated crucible. The lower figure, marked *fig.* 21, is a smaller crucible furnace for melting minute quantities of matter; its application follows readily from what has just been said.

In melting operations which are exclusively scientific, and not technical in their object, as, for instance, in ascertaining whether a substance can be melted by some of the fluxes at our command, we may in many cases make use of the *blowpipe* (*pl.* 31, *figs.* 62, 63). This consists of a brass tube inserted into one end of an expansion, *a*, into whose side is attached a smaller tube, *b*, with its extremity tapering to a very fine aperture. Air is blown from the mouth into the tube, and the extremity held above the wick of an alcohol lamp, so that the flame is driven into a horizontal pointed cone by the fine current of air: a very intense heat will thus be produced, and especially just before the point of the blowpipe. The substance to be tested is placed in small portions, in a hollow excavated in a piece of charcoal or clay, or held in platinum forceps, and the flame directed upon it. The object of the central chamber of the blowpipe, as just described, is to condense the moisture of the breath (the air too is condensed to a certain amount); there are sometimes several jet pieces, of different calibres, for slipping on *b*. Quite frequently the blowpipe consists merely of a tapering tube of brass, bent at right angles near the extremity.

The *oxy-ethereal lamp* (*pl.* 31, *figs.* 1 and 2) is capable of furnishing a heat equal in intensity to almost any with which we are acquainted. A is a glass lamp filled with ether; B a tube by which the air is brought into connexion with the inside of the lamp: C a fine metal tube, leading from a gasometer of oxygen, into the middle of the wick of the lamp. The lamp rests on a foot, D, through which the tube C passes. The wick of the lamp is covered by the ground-glass cap *a*, to prevent the evaporation of the ether when the apparatus is not in use. The heat of the lamp is capable of melting flint sufficiently to permit its being drawn out into a thread.

Other methods are employed when the heat required is not so intense as that we have just supposed. In many cases glass vessels well annealed may be used to much advantage.

2. *Apparatus for Converting Solid Bodies into Gaseous.*

For the above-mentioned purpose, much the same apparatus may be employed as is used in vaporizing liquids, namely, alembics, matrasses, and retorts. An operation of the kind may, for instance, have for its object the separation of bodies from each other. Thus, if it be desired to obtain the valuable mercury used in the construction of mirrors from its amalgam, the latter must be introduced into an iron retort (*pl.* 30, *figs.* 25 and 26). The first form differs from the second in having a small tube, *a*, opening into the head of the retort, for the purpose of more conveniently filling it, especially in cases where the neck must not be soiled by the material introduced. After filling the tube is to be closed by an iron stopper or other appropriate substance. When the bulb of the retort is introduced into a furnace and heated, the mercury passes over through the neck into a receiver, cooled by a stream of water, where it is again condensed. The tin remains in the retort, and both metals may thus be obtained separately. An apparatus of iron, provided with necks of leaden or glass tubes, may also be employed.

Similar retorts, of glass, porcelain, or clay, may be used when the heat required for vaporization is not so great. Should it simply be required to drive off, without collecting, the more vaporizable of two substances, we may frequently make use of the matrass, constructed of iron, porcelain, glass, or clay. The bottom of such a vessel, into which the mixture has been introduced, is heated, and the vapor allowed to escape through the open neck, the heat being so managed as always to be below what would vaporize the second substance.

Operations of this kind are frequently instituted by the chemist, and often find application in the arts. Thus zinc, in this way, may be driven off from its combination with many other metals, as it evaporates at a comparatively low temperature. Sulphur, also, is expelled in a similar manner, although the heat required is much less than in the case of zinc. An operation of this kind is called a *distillation* when the vapor thus produced becomes converted into a liquid on cooling, and a *sublimation* when this vapor assumes a solid state, apparently without previously passing through the liquid. Distillation takes place much more frequently in the case of liquids than of solids.

3. *Apparatus for Converting Liquid Substances into Gaseous.*

Nature exhibits to us on a large scale the conversion of liquid substances into gaseous. The evaporation of water is an instance of this kind. The most varied applications are made in Chemistry and the arts of that

property of liquids by which ebullition and consequent evaporation take place at certain temperatures. The ebullition or boiling of liquids consists in the fact that, after they are heated to a certain point, any additional increment, instead of being sensible to the thermometer, is expended in a combination with individual particles of the liquid. Thus water, when heated, gives indication to the thermometer of a rise of temperature up to 100° C., 80° R., or 212° F. Arrived at this point, the temperature remains fixed, provided that no change takes place in the height of the barometer, and the additional heat, instead of elevating the temperature, appears to combine with the atoms of water, expanding them to such a degree as to convert them into vapor or steam. The heat disappearing in this manner is said to become *latent*, as it cannot be indicated by the thermometer, although actually existing. For when this vapor or steam is led into cold water, its consequent condensation is accompanied by a rise in the temperature of the water corresponding to the amount of heat rendered latent. The boiling point of liquids, or the limit of the ascent of temperature at which ebullition takes place, depends greatly on the pressure of the atmosphere, boiling taking place sooner as the pressure is less. Thus, on the top of Mont Blanc, water boils at 187° F.

The process of *distillation* is generally employed to separate liquids of different boiling points from each other. Thus, in the fabrication of whiskey, after the fermentation of the mash, a mixture is produced from which the alcohol formed is to be separated, and obtained tolerably free from water. Pure anhydrous alcohol boils at 172.4° F., water at 212° F. On bringing the mash into a distilling vessel, and regulating the fire so that the temperature of the vessel shall not rise to the boiling point of water, the latter cannot pass over in any great quantity as vapor, while the spirit evaporates as soon as its own proper temperature has been exceeded. By cooling the tube terminating the distillatory apparatus, the vapor will be again condensed, and a liquid obtained which contains a much larger proportion of alcohol than before. The spirit will not be perfectly pure, inasmuch as some watery vapor will pass over; the amount of this will, however, be less as the temperature at which the operation is performed is lower.

It is very evident that we may separate vaporizable liquids from substances mixed with them, provided the latter require a higher temperature for vaporization than the former. The usual apparatus of distillation on a small scale is the retort; for larger operations, the alembic or the still. For most distillations of liquids we may use retorts of glass (*pl.* 30, *figs.* 25 and 26). In *fig.* 26 the liquid is introduced by means of a tube which is longer than the neck of the retort; in *fig.* 25 by means of a funnel through the head *a* in the bulb of the retort, this aperture being closed by a well ground stopper. The retort thus arranged is placed in the sand bath furnace (*fig.* 8). The space E forms a sand bath composed of tin: it is exhibited more fully in *fig.* 9. On its bottom is placed a thin bed of dry sand, and the retort, after being set on this, is surrounded by an additional quantity of sand. The bath has a notch cut out of the edge to receive the neck of the retort. The vessel or tube applied to the extremity of the neck of the

retort must be luted or cemented as closely as possible. The globes or matrasses (*figs.* 27, 28, and 29) are used for the purposes of receivers. In order that the neck of the retort may fit as accurately as possible into that of the globe, one of the latter is selected whose neck in one place is only a little wider than that of the retort to be set in it, and the neck of the globe broken off at this place with the help of a *splitting iron* (*fig.* 24). Of these irons there must be a considerable number at hand; to use them, one is selected fitting the neck of the globe, or indeed any other cylinder of glass, at a given place. It is then to be heated red hot and brought to the place in question, being held there for a few seconds. On removing the ring and pouring cold water on the heated glass, this will crack off evenly at the part which had been surrounded by the red hot iron ring. Having cut off the neck of the receiver to the proper length (it may possibly not require the operation at all), the neck of the retort is inserted into it, and the joining well luted. To support the receiver at the proper height, we may use a small table, as represented in *pl.* 30, *fig.* 10. The stem of this can move up and down in the cylindrical part, *a*, of the stand, and may be fixed at any height by a screw. The retort thus placed in the sand bath, with the receiver supported by the table, and generally resting on a ring of some kind for greater steadiness, heat is to be applied under the furnace and the receiver kept constantly cooled. The vapor arising from the ebullition, and passing over into the receiver, is there condensed again into a liquid.

For distillation on a larger scale we make use of the alembic. For this purpose the alembic is constructed in two different shapes. A very simple arrangement, and one long in use, is the small alembic represented in *pl.* 30, *figs.* 11 and 12. The vessel, *b*, in *fig.* 11 is intended to contain the liquid to be distilled. This is closed above by a head, *a*, shown more fully in *fig.* 12, well fitted to the body, and the junction luted to prevent the escape of vapor. On heating the bottom of the body, *b*, the vapor of the boiling liquid ascends into the head, and passes through the neck into the receiver, which is kept constantly cool. By means of an aperture in the head, closed by a glass stopper, fresh material may be introduced into the body without interrupting the operation.

A convenient arrangement for a distilling apparatus, which may be used for preparing distilled water, is shown in *figs.* 4 and 5. AB is the furnace over which the alembic, C, is heated. The part E fits exactly, with its under portion somewhat conical, into the opening of the alembic C (*figs.* 4 and 5); the head itself, D (*fig.* 5), has the following arrangement: The interior of the cylinder E, which is in connexion with the space of the alembic and receives the vapor, is closed like a roof above, as seen in *fig.* 5. At the base of this roof is the escape-pipe. The space D is filled with cold water. On bringing the water in the alembic, C, to boil, the steam ascends to the roof over F, and is here condensed by contact with the constantly cold walls, escaping by the pipe in the liquid form. In this arrangement the head itself forms the cooling apparatus.

A complete distilling apparatus, with a very convenient arrangement for cooling the vapors, is shown in *pl.* 31, *fig.* 3. A is an alembic, generally

constructed of copper; B the head, which, with the tube C and the cooling vessel EE, may more economically be constructed of tin. The space for the fire is at G. As soon as a liquid boils in the alembic A, its vapors ascend into the head B, and thence through the tube C into the cooling apparatus. The latter consists of a wooden box, DD, in which is set a tin cylinder, EE, running out below into a tube, F. Into the cylinder, EE, is inserted a smaller tin cylinder, *eeee*, closed below, down whose middle passes the tube of a funnel, *a*, reaching almost to the bottom. An uninterrupted stream of cold water is allowed to flow into the under cylinder through the funnel, *a*, and its tube. The vapors from the alembic, which enter the space inclosed between the walls of the inner and outer cylinder, are cooled, on the one side, by the fresh water introduced through the funnel *a*, and, on the other, by the water in the box DD. Fresh cold water is introduced into the bottom of this box by means of the funnel, *b*, and the pipe, *c*. As the water in the inner cylinder, *eeee*, becomes heated, it flows through a small pipe into DD, and thence, with the heated water of DD itself, out at *a*. It will be remembered that water, as it becomes heated, becomes specifically lighter, for which reason the warmest water will always occupy the highest position in the vessel containing it. The cold water, also, introduced through the funnels, occupies the lowest part of the several vessels, and displaces the heated water previously occupying that same position. The vapors from the body of the apparatus are condensed so perfectly by this arrangement, that a liquid, hardly lukewarm, flows out as the result through the pipe F.

All distilling apparatus, properly so called, have for their end the recovery of the liquid vaporized. It often happens, however, that our only object is to collect some solid dissolved in a liquid. Thus, when we wish to obtain solid salt from a solution of salt and water, the water is here of no use. In such cases, instead of distilling vessels, we make use of very shallow and wide vessels, in which the liquid may come as much as possible in contact with the air. Evaporating dishes of this kind are represented in *pl.* 30, *figs.* 35 and 36.

4. *Instruments for Investigating Matter which is Gaseous at Ordinary Temperatures.*

We have already gone into some detail upon the methods of converting solids into liquids, and liquids into the gaseous condition. It remains to see whether the reverse may not be possible, whether it does not lie in our power to convert a gas into a solid, or at least into a liquid. With the means commanded by modern chemistry, there are now only three elementary substances which cannot be changed from their gaseous condition: oxygen, hydrogen, and nitrogen. The method of condensing gases will readily suggest itself from what has been said on the subject of boiling. Since the cause of the gaseous condition of a solid or liquid is to be found in the combination of heat rendered latent, and since, when this latent heat is

withdrawn, the vapor again becomes a solid or liquid, we are fairly entitled to suppose that those substances which are gaseous at ordinary temperatures, owe this property to their latent heat; and we may legitimately presume that by removing this latent heat the conversion desired may be effected. The means at our command for removing latent heat consist in the application of an extraordinary pressure, since, in proportion to the amount of compression exerted, latent heat is rendered sensible, and thus by pressure alone may many gases be condensed into liquids. A second method is afforded by the use of the so-called freezing mixtures. By mixing together certain substances, an extraordinary amount of cold may be produced, and many gases rendered liquid by such artificial congelation. In cases which are very difficult to reduce, both methods may be applied simultaneously. Thus the gas may be placed in a cylinder of metal, in which fits a piston, air-tight, and depressed with great force at the same time that the cylinder is immersed in a freezing mixture. The condensation of carbonic acid gas may serve as an illustration of this method, as also of quite a peculiar mode of producing a great degree of cold. Carbonic acid gas is well known, by its effects at least, to everybody; it is one of the substances formed by the combustion of coal, and one which is developed in the fermentation of liquids containing sugar, as beer and wine, its presence being indicated in the frothing and foaming of these and similar liquids, when the cork inclosing them is withdrawn. Carbonic acid, to become liquid at the temperature of freezing water, or 32° F., requires a pressure of sixty atmospheres, and at a temperature of 86° one of seventy-three atmospheres. The apparatus employed is represented by *pl.* 31, *fig.* 6. A is a cylinder of cast iron into which bi-carbonate of soda must be introduced before the piece C is inserted. At the same time a copper vessel is to be introduced into the cylinder containing as much sulphuric acid as will suffice to expel all the carbonic acid gas from its combination with the soda, by combining itself with the latter. The iron piece C, having a longitudinal canal, is now screwed into the cylinder. The copper tube, *mm*, is so inserted into the side of C as to communicate with its canal. In a similar manner this tube opens by its other extremity into the piece D of the smaller iron cylinder B, similar in construction to C, and having its inner canal in connexion with the inside of the cylinder. The iron pieces, *c*, *d*, are inserted into the similar pieces C and D, and through them pass the screws, *a*, *b*, by means of which an attached valve *fig.* 7 (upside down in the plate), may be so adjusted, that the openings of the tube, *mm*, may be shut or opened at pleasure. The clamps *n*, *n*, and E, E, hold the two vessels tightly together. The apparatus being thus arranged, the opening of the tube, *mm*, in C is closed by depressing the valve by means of the screw *a*. The apparatus is to be inclined until the sulphuric acid placed in the copper vessel may flow over the bi-carbonate of soda, and thus produce a chemical decomposition. Both valves are now opened, or that connected with the screws *a* and *b*, and the carbonic acid generated passes into the cylinder, B, cooled by ice. So vast an amount of gaseous carbonic acid is generated from the bi-carbonate of soda, that this becomes fluid from the pressure produced by

its own abundance. As soon as the action of the acid on the soda is supposed to be completed, the opening of B is closed by means of the valve at *b*, and the apparatus taken apart. On opening the valve at *b*, the liquified carbonic acid will flow out as soon as the cylinder B is inverted. The walls of the vessel must be strong enough to resist a pressure of sixty atmospheres, and the entire experiment is at all times dangerous. In an experiment of the kind, instituted in Paris by Thilorier, the apparatus burst and killed one person, and severely wounded several others. The liquified carbonic acid evaporates so rapidly when the pressure is removed, that a great part of it becomes solid, the part converted into gas rendering so much of the heat latent as to freeze the rest. In the condensation of carbonic acid gas, we have, therefore, an example of a gas condensed to a liquid by pressure, and, at the same time, the condensation of a liquid by cold into a solid body, the acid being actually frozen by the rapid abstraction of the heat required by the evaporation of the gas. Thilorier obtained solid carbonic acid in a white mass, similar to a ball of snow. By combining solid carbonic acid and ether, the acid becomes at first liquid, and then evaporates along with the ether; a cold of such intensity is thus produced as causes the thermometer to sink to 180° below the freezing point of water. Faraday has obtained a still lower temperature of 175° below the zero of Fahrenheit, or 207° below the freezing point of water, by the action of solidified carbonic acid in a vacuum. By the use of carbonic acid, Faraday succeeded in liquifying many other gases which until then had resisted every effort. Oxygen, hydrogen, and nitrogen, however, resisted every attempt of the kind, even when combined with enormous pressure. Liquified nitrous oxyde boiled on the application of the carbonic acid.

Many gases may be liquified on a small scale in bent tubes (*pl.* 30, *fig.* 43), at one of whose extremities a strong glass bulb is blown. Supposing the bi-carbonate of soda to be introduced into the bulb, and the sulphuric acid kept in the angle of the bend until the open end of the tube is melted together; on bringing the two in contact a rapid evolution of gas ensues, which results as before. One end, of course, must be placed in a freezing mixture.

II. Elementary Condition of Matter, or the Elements.

Only a small amount of the matter surrounding us is in its elementary condition. Of the gaseous elements, two, oxygen and nitrogen, mixed in proportions of twenty-one to seventy-nine, form atmospheric air. Of liquid elementary substances, mercury is the only one which occurs in nature. On the other hand, many of the solid elements occur uncombined, as gold, silver, iron, platinum, &c. All these substances, however, occur more frequently in a compound state, or united together, and by far the greater number of these chemical combinations consist of one element, combined with one or more others in a definite proportion. The material composing

the substance of plants and animals almost always consists of such combinations. Hence we see that to ascertain the properties of an elementary body, we must carefully separate it from its combinations. In the following articles we shall present the principal methods of doing this for a number of these elements.

1. *Apparatus for Obtaining the Gaseous Elements.*

Oxygen gas, while in a state of mixture, and not of combination, is a principal constituent of atmospheric air and the great instrument of organic vitality. Inhaled into the lungs, or brought into contact with the respiratory apparatus of animals in general, whether skin, gills, lungs, or branchiæ, it furnishes the chief means for purifying the blood by eliminating the effete carbon. This gas, however, does not exist alone. The stimulus to these various organs would, in many cases, be too great in the case of pure oxygen alone; we therefore find this gas diluted with a large proportion of nitrogen.

So intimate, however, is the mixture of oxygen and nitrogen in the air, that it is impossible to separate them by mechanical means; it therefore becomes necessary to do this by chemical agencies, which may also be applied in obtaining oxygen from other mixtures or compounds, the latter, in fact, being by far the best sources from which to procure the gas in question. Oxygen combines with almost all the other elementary bodies; at least, the only one in respect to which this fact has not been ascertained, is fluorine. To obtain oxygen pure, therefore, we may use one of several different combinations. Thus, for instance, we may select the protoxyde of mercury, a reddish substance, known in the arts as red precipitate. A sufficient quantity of this is introduced into the retort, *b* (*pl.* 31, *fig.* 13), the neck of this being firmly held by the clamp of the stand C. The neck of the retort terminates in the balloon, *c*, in which it is secured by a cork. From the second opening of this balloon a bent tube, *d*, passes into the water of the trough A. On one of the shelves of the trough is placed the receiver B, first filled with water, and then inverted so as to keep it entirely full; the end of the tube, *d*, must be just under the bottom of the receiver B. The inversion of the receiver, when filled with water, will be more practicable if the open end be closed by a plate of ground glass, which is to be removed under the surface of the water in the trough. After seeing that all the joints are rendered perfectly air-tight by means of the proper luting, a red heat is applied to the bottom of the retort by means of the spirit lamp *a*. At the temperature of a low red heat, the red oxyde of mercury is decomposed into its elements, and the gaseous oxygen first drives out the contained air through the conducting tube, *d*; for this reason the first bubbles, when formed, must be allowed to escape and not pass into the receiver. When all the air has been expelled, the succeeding oxygen passes from the end of the tube *d*, and rising through the water in a succession of bubbles, occupies the top of the receiver, displacing as much water as the

space it occupies. When the receiver, B, is filled, it is to be removed to another shelf, and replaced by a new receiver, prepared like the last.

The philosophy of the operation by which the oxygen is liberated is as follows: Oxygen has a very great tendency to maintain the gaseous condition, and we have seen that the ordinary agents of cold and pressure, as usually applied, have been unable to effect its condensation into a liquid. In this case chemical affinity has done what the other agents failed to accomplish, namely, changed it from a gas into a solid. The accompanying mercury, also, is in a solid state, instead of its ordinary liquid condition. Heat, however, overcomes this combination by which the two elements are solidified, and the elements, expanding, resume their more natural state. The mercury is liquified; the oxygen converted into gas, which then passes over. The heat applied must of course not be sufficient to vaporize the mercury: this requires a temperature of 660°F.

A more economical way of procuring oxygen is to employ black oxyde or deutoxyde of manganese in the apparatus given in *pl.* 31, *fig.* 60. The iron retort, C, is filled with manganese, and placed in the furnace, B. In its mouth is inserted the bent iron gun-barrel or leaden tube, leading to the pneumatic trough, D. On heating the retort to redness, one portion of oxygen is liberated from its combination with the manganese, and driven over to the trough, where it is to be collected with the precautions described in the preceding paragraph.

Hydrogen is likewise a gaseous elementary body. While oxygen occurs abundantly in the atmosphere combined mechanically, and in the solid and liquid constituents of the earth combined chemically, hydrogen is never met with but in the latter state of combination. We may indeed make a slight exception for the minute quantity discernible at times in the atmosphere, the result probably of volcanic action. It is most abundant in a combination with oxygen forming water. The proportions of these two gases, in water, are one part of hydrogen and eight of oxygen by weight, and two of hydrogen and one of oxygen by volume. The readiest way of obtaining hydrogen consists in the decomposition of water. Pieces of zinc are introduced into the gas generator, A (*pl.* 30, *fig.* 55), the vessel filled about two thirds full of water, and sulphuric acid poured in by degrees through the funnel tube, D. The water standing a little higher than the lower end of the funnel tube D, closes this tube, so that the gas, when generated, can only escape through the tube, CC′, which is inserted into the cork stopper of the vessel A. In the case of this generating vessel, and, indeed, in all apparatus used for developing gases, some arrangement is employed to prevent any danger of bursting by the stoppage of the conducting tube. This purpose is accomplished in our illustration by means of the funnel D, out of which the liquid will be forced by any accumulation of gas in A. Another contrivance, called *Walter's Safety Tube* (*figs.* 44 and 45), is intended for the same purpose. Water, or any more appropriate liquid, is poured into the leg *a* (*fig.* 45), so as to fill the bulb except about one third. A safety tube of this character is inserted into the corked stopper of the generating apparatus instead of the funnel D (*fig.* 55). Should any

obstruction occur in the conducting tube, the gas escapes by the safety tube. The column of liquid which under satisfactory circumstances stands about *e*, and in the tube at *b*, is then driven back into the bulb. The gas then ascends through the liquid in the bulb in the form of bubbles, and thus escapes. The arrangement of *fig.* 44 may serve to bring about the same result in regard to the conducting tube, by attaching to the latter an apparatus similar to that of *pl.* 31, *fig.* 61 (the figure is inverted in the plate). The end, *a*, of the latter apparatus is to be placed in the cork of the generating vessel. *Pl.* 31, *fig.* 56, exhibits still another kind of gas generator, with two openings, one of them receiving the funnel tube, the other the gas conductor. It frequently happens that gases must be freed from the watery vapor with which they are combined. This is done by interrupting the gas conductor by a wider tube (*fig.* 56), first partly filled with cotton, and next with pieces of chloride of calcium, the latter substance absorbing watery vapor with great eagerness. The tub B, in *pl.* 30, *fig.* 55, is the *pneumatic tub* or *trough* as generally used by chemists. It has at *cc* a shelf, provided with grooves and holes, under some of which small funnels are attached. Water is poured into the trough to a height of an inch or two above the shelf. The receivers are to be filled with water, and then inverted and placed on the shelf, over one of the apertures. The end of the tube communicating with the gas-generating apparatus is to be brought under one of the funnels, which then guides the gas in its ascent through the water to the top of the receiver. The general operation is the same as already described. The receiver may also be so placed on the shelf as to project by less than half its diameter, and the end of the gas tube brought under the open space. In this way the holes and funnels may be dispensed with.

Chlorine, at ordinary temperatures, is a gas of a yellowish green color, and very corrosive, and poisonous when inhaled. This gas is one of the constituents of common salt, which is a combination of chlorine with the metal sodium, forming, in chemical nomenclature, the chloride of sodium. Chlorine is very conveniently obtained from muriatic or hydrochloric acid, an acid procured in large quantities in the manufacture of carbonate of soda from common salt. This hydrochloric acid is a combination of chlorine and hydrogen, formed under the conditions required for separating the chlorine from common salt. Fill the flask A (*pl.* 31, *fig.* 14) nearly half full of hydrochloric acid, and into it drop some substance rich in oxygen, as the peroxyde of manganese: the oxygen of the latter will combine with the hydrogen of the acid, forming water, leaving the chlorine free to pass over, and to be collected in a receiver, as already described. To accelerate the operation, a spirit lamp is placed under the flask, which is fixed by the two rings, *a* and *b*, of the retort stand, C. The apparatus (*fig.* 14) here described is applicable to many other purposes.

2. *Apparatus for Procuring the Liquid Elements.*

Among the simple substances entering into the composition of our earth, and its contents, only two are liquid at ordinary temperatures; the non-metallic *bromine*, and the metallic *mercury*. The latter is sometimes found native, but more frequently in its combination with sulphur as cinnabar. The following method may be employed to separate the metal from the sulphur. Mix the cinnabar with iron filings, and place it in an iron retort (*pl.* 30, *fig.* 25). The retort is then to be brought to a red heat, as in a wind furnace (*fig.* 3). At this red heat the sulphur combines with the iron filings, forming a sulphuret of iron, leaving the mercury in a metallic condition to be carried over in the form of vapor into the neck of the retort, and thence to an appropriate receiver. The receiver being kept constantly cool, the vapor of the mercury is condensed, and the metal thus obtained in its ordinary liquid state.

3. *Apparatus for obtaining the Solid Elements.*

The methods to be employed for separating those elementary bodies which are solid at ordinary temperatures, vary very much with the different combinations which have to be considered. Only a few of these methods of manipulation can be referred to in the following pages. *Pl.* 31, *fig.* 8, represents the apparatus for obtaining *phosphorus*. BC is a furnace, into which an iron retort, A, may be introduced. The retort must be filled with a mixture of charcoal dust and phosphate of lime. This latter salt is obtained from burnt bones, by several intermediate stages of manipulation. The phosphoric acid at a red heat is decomposed, and the oxygen having then a greater affinity for the carbon of the charcoal, forms with it carbonic acid and carbonic oxyde, leaving the phosphorus in the form of a vapor, which is carried over and condensed in the bent upper tube, *b*. The end of the tube dips a few inches below the surface, *ccc*, of the water, placed in a flask, D, closed above with a cork, through which passes the tube *d*. The phosphorus thus condensed in the tube flows into the water, where it accumulates at the bottom. Great care is necessary to prevent any access of atmospheric air, as the contact of the two would be followed by a combustion resulting from the combination of the phosphorus with oxygen, and the consequent formation of phosphoric acid. The tube *d*, which, passing through the cork, does not reach quite to the surface of the water, serves to permit the escape of the various gases, as carbonic oxyde and acid, which are formed during the operation. Phosphorus is a non-metallic substance having much the appearance of white wax, and requires to be handled very carefully on account of its inflammable character.

Preparation of Sodium. Common salt, rock salt, sea salt, all one and the same substance, consist of two simple bodies combined in definite proportion, the one a gas, chlorine, the other a silver white metal, sodium.

The latter has so great an affinity for oxygen as to take it from almost any combination possible to be formed. Thus, if sodium be thrown on water, a part of the latter will immediately be decomposed, its oxygen uniting with the metal to form the alkali soda, and the hydrogen escaping in the form of a gas. The combination, however, of sodium with water, is attended by the development of so much heat, as to inflame the liberated hydrogen, which immediately unites with the oxygen of the atmosphere. In the fabrication of hydrochloric acid from common salt, the base of the latter is finally obtained in the form of an oxyde, or as the alkali soda, known as caustic soda. This is, however, not obtained in its separate form without further manipulation, being exhibited as a carbonate. It is from this carbonate of soda that the metal may be obtained by means of the furnace DD (*pl.* 31, *fig.* 9). The wrought iron vessel, A, is to be laid on the furnace on the two cross-bars, *f*, *f*. One of the iron bottles used to contain the mercury of commerce may be used as the vessel in question. Into the opening of this bottle, a gun-barrel, about six inches long, must be firmly fixed, and the bottle partially filled with a mixture of dry carbonate of soda and charcoal, and placed in the furnace, which must have a very powerful draught. The opening, CC, through which the bottle is introduced into the furnace, is closed tight by a piece of fire-brick, any interstices being luted or cemented. The short iron gun-barrel, *a*, passes through the brick. When the vessel has been brought to a red heat, the copper vessel, B, is joined to the gun-barrel, *a*, by a short neck in the upper portion, and partly covered by a wire frame. Opposite to the neck just referred to, is a short copper cylinder at *e*, extending to the wire frame, the object of which is to permit the introduction of an iron rod through B into the tube *a*, for the purpose of freeing it from any obstruction. The tube, *d*, is attached to the side of B, near its upper part. This copper vessel, B, consists of two portions which can be lifted apart. The lower part embraces the upper as far as the roof, *cc*, which is soldered nearly in the middle of the upper part of the vessel. The lower part of the vessel is now to be filled about two thirds with petroleum or naphtha, the upper part slipped in, and the vessel thus adjusted, brought into communication with the iron tube *a*. The wire frame must be kept constantly cold by means of snow or ice, and the heat of the furnace raised to a great intensity. At a strong red heat the carbonate of soda is decomposed into carbonic acid and oxyde of sodium, and the carbon of the charcoal combines with the oxygen of the oxyde, forming carbonic oxyde and carbonic acid, leaving the metal free. The gases pass over through the tube into the cold copper vessel; the metal in the form of vapor also passes over, and is condensed into small globules, which fall to the bottom of the naphtha. The naphtha being a hydrogen compound, free from oxygen, prevents the access of the latter gas to the metallic sodium. A nearly similar process may be used to obtain some other metals, as potassium, from their combinations.

Method of obtaining Metallic Iron. Our object in this place is not to treat of the reduction of iron on the large scale from its ores, but simply to mention the chemical process by which we are enabled to ascertain the

amount of pure metal in a certain combination, such as the protoxyde or peroxyde.

For this experiment we may use the apparatus represented in *pl.* 31, *fig.* 58. A glass tube, *b*, constructed of glass of difficult fusion, and having a bulb blown in the middle, has small brass cocks attached to each end by caoutchouc tubes. By means of these cocks the tube is to be attached to an air-pump, and afterwards weighed when all the air has been removed. Note must be taken of the loss of weight in the tube, produced by the exhaustion of the air. Into the bulb of the tube is now to be introduced a quantity of still hot oxyde of iron, heated over a Berzelius lamp. This lamp (*fig.* 11), one of the most convenient of all chemical apparatus, is constructed as follows: *a* is an annular vessel for containing alcohol, the space within the annulus being occupied by a cylinder, *c*, in communication with the vessel. The cylinder is double, one within the other: an annular bottom is soldered between the two cylinders, thus inclosing a space which is brought into communication with the space of the vessel *a*, by means of two short tubes passing between *a* and *c*. A tubular lamp-wick is placed in this space between the two cylinders, and kept constantly moistened by the alcohol flowing from *a* through the tubes; this wick may be regulated, as to height, by a screw, *f*. The space within the inner cylinder is open at both ends, thus allowing the introduction of a constant stream of fresh air into the centre of the wick when burning. The flame is surrounded by the small chimney *g*, made of sheet iron, and intended to increase the draught. The lower slide, *d*, of the stand, *e*, carries the lamp, and another above it the vessel to be heated, in this instance the crucible *b*. Both slides may be set at any height along the vertical rod of the stand, by means of lightning-screws. The iron pincers (*fig.* 64) are used to handle the heated vessel.

If now, as already mentioned, a sufficient quantity of oxyde of iron, as from thirty to fifty grains, be removed from the crucible into the tube *b* (*fig.* 58), the oxyde of iron is to be permitted to cool in a vessel filled with dry air; the cocks are to be again attached, and the air pumped out, after which the tube is to be again weighed. The excess of weight in the latter weighing will represent the weight of the oxyde introduced. After again removing the cocks the glass tube is to be connected by dried cork or caoutchouc tubes, with the rest of the apparatus shown in *fig.* 58. Here A is a gasometer filled with hydrogen; B a flask half full of sulphuric acid; *a* a bulb tube containing chloride of calcium; then comes the tube with the oxyde of iron, and to this succeeds the tube *c*, likewise filled with chloride of calcium. After this series of tubes has been connected air-tight by means of the glass conducting tubes, *f*, *f*, *f*, the cock, *e*, of the gasometer is to be opened. The hydrogen passes out in bubbles through the sulphuric acid into the top of B, thence through *f* into the first chloride of calcium tube *a*. The sulphuric acid through which the gas is driven abstracts from it the mingled watery vapor; this, however, is done more completely by the chloride of calcium, the gas arriving perfectly dry in the tube *b*, where it comes into contact with the oxyde of iron. As soon as all air in the

apparatus has thus been replaced by hydrogen, the lamp (*fig.* 11) is to be brought under the bulb of *b*, and the oxyde of iron heated to a slight glow. When this has ensued the hydrogen combines with the oxygen of the oxyde to form water, which is carried by the succeeding hydrogen into the calcium tube *c*, and there absorbed. After a time the oxyde in *b* will be found completely reduced to metallic iron. The lamp must now be removed and the whole apparatus allowed to cool. The bulb containing the iron is again to be provided with the cocks and the air exhausted; on weighing it, the difference between this weighing and the preceding will be the weight of the oxygen, and the difference between this last weighing and the first will be the weight of the iron. In experiments tending to great accuracy, the chloride of calcium tube, *c*, is likewise weighed before and after the operation. This tube will be increased in weight by the water absorbed, and as the composition of water is well known, the amount of oxygen in the estimated weight of water must coincide with the amount lost by the oxyde of iron.

III. The Elements and their Combinations.

It has already been remarked that by far the greater number of bodies surrounding us are chemically compound in their character. Of this we are abundantly convinced by the possibility of reproducing certain compounds from the elements which we had obtained from them. In this way we are enabled very conveniently to form certain substances whose composition has been first ascertained by analysis.

It is a very general, if not universal law, that a simple body combines only with another simple body, rarely with one that is already compound. In this manner are produced chemical combinations of the first degree, or *binary compounds*, containing two elements. When two binary compounds unite, a *ternary compound* is produced. The number of these ternary compounds far exceeds that of any of the others.

Different names are given to particular classes of these compounds. Thus the binary compounds of oxygen with any other element are either oxydes or acids. When the same element combines with oxygen to form an oxyde in more than one proportion, that containing the least quantity of oxygen is called the protoxyde; the next, deutoxyde; the third, tritoxyde; &c.: the highest proportion gives us the *peroxyde*. The acid combinations of oxygen have the name of the combining element with a termination of *ic*. Thus nitrogen and oxygen form nitric acid. If there be two acid compounds, the one with least oxygen ends in *ous*, as nitrous acid.

The most remarkable law of chemistry, and at the same time the one on which the whole science depends, is, that the elements always combine in definite proportions by weight. An entirely new attribute is thus added to our previous idea of an element, namely, its capacity of combining, according to definite laws, with all the others. Thus carbon never combines with oxygen in any other ratio than that of 6 : 8, while sulphur

combines with oxygen in the proportion of 16 : 8. The same numbers, six and sixteen, expressing the ratio of combination for carbon and sulphur with oxygen, express also the ratio of their mutual combination. Their ratios experience no other modifications than those obtained by multiplying the first or second term. This same law of definite proportions applies not only to carbon, sulphur, and oxygen, but to all elements. Knowing, then, the ratio in which all the elements combine with oxygen, we shall have the ratio of their combinations with each other. This ratio may be expressed either by the numbers themselves, or by their multiplication into some definite progression. This progression may be the series of numbers from one to five, and in some cases fractions intermediate to these. The numbers thus obtained for the different elements are known by the terms, *atomic weights*, *combining numbers*, or *chemical equivalents*, and were first established with remarkable accuracy by Berzelius, and afterwards corrected by other chemists. In the following table we present the elements already known to chemists, with their symbols and equivalents. For greater convenience we have given two series of equivalents, the one where hydrogen is taken as unity and oxygen as 8, the other assuming 12.5 as the equivalent of hydrogen, and 100 as that of oxygen.

The equivalents adopted in the table are taken from the third volume of the fifth (German) edition of Berzelius' Treatise on Chemistry, a few more recent determinations by Marignac being added. Many chemists consider the equivalents of Calcium, Magnesium, Iron, Silver, Mercury, Sulphur, and some others, as exact multiples of that of Hydrogen ; but experiment has not yet established this point in a perfectly satisfactory manner.

Tantalum, Niobium, and Pelopium occur associated in nature, and have not yet been perfectly separated. The name Columbium was applied to the metal obtained from the Columbite of Connecticut by Dr. Wollaston. Rose has recently ascertained its identity with Niobium, and it is therefore better to drop the old name, which has only been employed by American writers.

The symbols are abbreviations of the English or classical names, employed for greater convenience of reference. Those elements to which no equivalent is appended, have either been discovered quite recently, or else elements supposed to be pure, have been ascertained to be compounded with some other elements, and the equivalents previously determined must therefore be rejected.

The circumstances under which chemical combinations of simple bodies take place, are very various. Temperature exerts a great influence, although its action differs much under different circumstances. Many bodies require to be cooled in order that a combination may take place. Thus chlorine only combines with water at and under a temperature of about 32° F. ; others combine directly at ordinary temperatures, whenever brought into communication, as potassium and oxygen. By far the greater number of combinations, however, are produced through the instrumentality of heat, while others again are decomposed by the same agency. Of all simple elements, oxygen exhibits the greatest tendency to combine with the rest,

and it is combinations of oxygen which constitute the greater portion of the mineral, vegetable, and animal kingdoms. Many compounds of oxygen are produced at elevated temperatures alone. Under these circumstances, the heat which is liberated in almost all chemical combinations, and especially those between elements having a great affinity for each other, is set free in large quantities, thus serving to heat fresh matter. Many substances do not combine quite so readily with each other, and with many the temperature must be elevated to a very great degree to bring about the desired result.

List of the Elements, with their Equivalents and Symbols.

Names.	Symbols.	H = 1.	O = 100.	Names.	Symbols.	H = 1.	O = 100.
Aluminum . . .	Al.	13,67	170,9	Nickel	Ni.	29,54	369,3
Antimony . . .	Sb. (1)	129,03	1612,9	Niobium	Nb.		
Arsenic	As.	75,10	938,8	Nitrogen. . . .	N.	14	175,0
Barium	Ba.	68,54	856,7	Norium	No.		
Bismuth	Bi.	212,85	2660,7	Osmium	Os.	99,40	1242,6
Boron	B.	10,89	136,2	Oxygen	O.	8	100
Bromine	Br.	79,96	999,6	Palladium . . .	Pd.	53,23	665,4
Cadmium . . .	Cd.	55,73	696,7	Pelopium . . .	Pe.		
Calcium	Ca	20,12	251,6	Phosphorus. . .	P.	31,36	392,0
Carbon	C.	6,	75,0	Platinum . . .	Pt.	98,56	1232,0
Cerium	Ce.	47,26	590,8	Potassium . . .	K. (7)	39,10	488,8
Chlorine	Cl.	35,45	443,2	Rhodium. . . .	R.	52,15	651,9
Chromium . . .	Cr.	26,30	328,8	Ruthenium. . .	Ru.	52,15	651,9
Cobalt	Co.	29,48	368,6	Selenium . . .	Se.	39,61	495,2
Copper	Cu. (2)	31,64	395,6	Silicon	Si.	22,21	277,7
Didymium . . .	D.	49,60	620,0	Silver	Ag. (8)	107,96	1349,6
Erbium	E.			Sodium.	Na. (9)	23,17	289,7
Fluorine	F.	19,0	237,5	Strontium . . .	Sr.	43,67	545,9
Glucinum . . .	G.	13,93	174,2	Sulphur	S.	16,05	200,7
Gold	Au. (3)	98,16	1229,1	Tellurium . . .	Te.	64,13	801,7
Hydrogen . . .	H.	1	12,5	Tantalum . . .	Ta.		
Iodine	I.	126,88	1586,0	Terbium	Tb.		
Iridium.	Ir.	98,56	1232,0	Thorium	Th.	59,50	743,8
Iron	Fe. (4)	28,04	350,5	Tin	Sn. (10)	58,82	735,3
Lantanum . . .	La.	47,04	588,0	Titanium. . . .	Ti.	24,12	301,5
Lead	Pb. (5)	103,56	1294,6	Tungsten. . . .	W. (11)	95,06	1188,3
Lithium	L.	6,52	81.6	Uranium	U.	59,42	742,8
Magnesium . .	Mg.	12,64	158,1	Vanadium . . .	V.	68,55	856,9
Manganese . .	Mn.	27,56	344,6	Yttrium	Y.		
Mercury	Hy. (6)	100,09	1251,2	Zinc	Zn.	32,52	406,6
Molybdenum. .	Mo.	46,0	575,0	Zirconium . . .	Zi.	33,57	419,7

(1). Stibium.
(2). Cuprum.
(3). Aurum.
(4). Ferrum.
(5). Plumbum.
(6). Hydrargyrum.
(7). Kalium.
(8). Argentum.
(9). Natrium.
(10). Stannum.
(11). Wolfram.

1. *Apparatus for Combining Gaseous Elements.*

Combination of Hydrogen with Oxygen. To ascertain the ratio in which these two gases combine, we make use of an instrument termed an *eudiometer* (*pl.* 31, *fig* 66). This is especially employed to determine the character of a gas with respect to its amount of oxygen. The eudiometer is essentially a graduated glass tube, into the upper end of which two wires have been inserted opposite to each other. A tube of this character is often surrounded, excepting two longitudinal strips allowing the graduation to be seen, by a metal casing. This tube is first inverted and filled with water, then erected under water and raised, so that the lower part of the tube may still be immersed, the tube itself remaining filled with water. Pure hydrogen gas is now to be introduced into the tube by the ordinary method of manipulation, filling it to a certain amount, as twelve degrees ; if half this volume or six degrees of pure oxygen be now introduced, and the charge of a Leyden jar passed through the mixed gases by means of the two metal wires, an explosion will take place, sometimes sufficient to shatter the tube. If the gases be perfectly pure, the water will immediately rise to the top of the eudiometer, the contained gases having all been combined to form water. If seven degrees of oxygen had been taken in the above experiment, then there would have been one degree of oxygen left in the tube after the explosion, just as we would have had a portion left of hydrogen had this gas entered in greater proportion than the one mentioned. Here we perceive that chemical combinations are all definite, and that an excess of one ingredient over the proper proportion, is indicated by this excess remaining free.

2. *Apparatus for Combining Liquid Elements with Gaseous.*

As already mentioned, mercury and bromine alone of all chemical elements, occur in the liquid condition. Mercury can be combined directly with gaseous oxygen. If this metal be boiled for several months in a matrass (*pl.* 30, *fig.* 27), whose neck for this purpose should be several feet long, the mercury will be gradually changed into a red crystalline powder, which, in 108 parts by weight, contains 100 of mercury and 8 of oxygen. It is this *oxyde of mercury* which by heating is again decomposed into mercury and oxygen, and may therefore be used in the preparation of pure oxygen. More advantageous processes for obtaining this oxyde are known in the arts, more complicated, however, in their character.

3. *Apparatus for Combining Solid and Gaseous Elements.*

Among the gaseous elements, oxygen and chlorine, as also iodine, bromine, and sulphur, when converted into vapor by heat, combine with almost

all other elements; at least in many cases all that is necessary to effect this combination is the heating of the latter. The apparatus employed for the purpose is generally very simple, consisting principally of crucibles, tubes of porcelain and glass, capsules, matrasses, flasks, and retorts.

In most experiments, however, instituted with the gases proper, a large quantity of these is required to be kept in convenient vessels. Such vessels are known as *gasometers*. They are so contrived as to permit a convenient filling in of the gas, as well as its safe preservation for a considerable length of time when not required for use. To this must be added a facility in extracting as much or as little as may be needed for experimental purposes. *Pl.* 30, *figs.* 58 and 59 represent a gasometer of the earlier construction. The entire apparatus, consisting of two vessels, is first filled with water, and the cock, Z, closed, so that the water in the flask cannot flow out through the tube G. The gas conductor is attached to the tube C, through which the gas generated is allowed to enter. The cocks O and *o* are opened, R remaining closed. As the gas enters through the tube CO into the vessel B, and rises in single bubbles through the water in this vessel, the water is driven out through the open cock, *o*, at the bottom. As soon as B is filled with gas, the cocks, O, *o*, are closed, and the apparatus retained in this state until the gas is required for use. To force out the gas when wanted, the cock Z must be opened. The air which presses on the flask through the tube T, after the openings E (*fig.* 59) and F (*fig.* 58) have been closed, drives the water through the bent tube, G, into the gas-vessel, B, here displacing the gas, and driving it out through R*t* when the cock R is opened. The gas may thus be driven into another vessel, as shown in *fig.* 59, by connecting the extremities of the two brass tubes, *t'*, *t'*, by caoutchouc.

The gasometers of more recent construction are, however, far more convenient (*pl.* 31, *figs.* 4 and 5). The first figure gives a back, and the second a side view of the instrument: A and B are cylindrical vessels made of copper or zinc. The upper one is connected with the lower by posts and several tubes. The rods *e* and *bb* are tubes, provided with cocks, by means of which the communication through the tubes between the two vessels may be interrupted or restored at pleasure. One tube, *bb*, reaches nearly to the bottom of the vessel A; the other, *e*, ends on the cover to which it is soldered. The glass tube, *cc*, is so attached to the outside of the lower vessel, as that one end communicates with the interior of A at the top, and the other end at the bottom. At the bottom of A there is an escape pipe, C, capable of being closed by a screw lid. To use the apparatus, the cocks at *e* and *b* are first opened, and the apertures in (*fig.* 5) *a* and (*fig.* 4) C are closed by their cover. Water is poured into the upper cylinder, which enters through the tube *bb* into the vessel A, while the air ascends through the tube *e*, and escapes in the form of bubbles. When the entire apparatus is filled with water, all the cocks are closed, and the screw C opened. As the air has no access to the space in A, its pressure on the small surface at *a* or C keeps the water in equilibrium, so that this cannot escape. The tube from the gas-generating apparatus is introduced into C, and the gas allowed to ascend. Occupying the highest part of A, the gas displaces the water,

driving it out through the aperture C (or *a*). The tube *c* serves to indicate the height of the water in the vessel A, and consequently the volume of gas. When the gasometer is filled, the opening C is closed. When the gas is required for use it escapes through a tube attached to the right of *fig.* 5, which is provided with a cock. On pouring water into B, and opening the cock *d*, the water will descend to the bottom of A and press upwards against the gas. This will then readily flow out on opening the cock of the lateral tube.

It has already been mentioned that oxygen and hydrogen unite in proportions of one measure of the former and two of the latter to form water, whenever the electric spark is passed through the mixture. A mixture in these proportions is known as the explosive gas. The union of the two gases takes place with an extraordinary development of heat, and in the moment in which watery vapor is formed by the combination so sudden an expansion is produced, that large quantities of gas sometimes involve serious explosions. The heat generated in this combination is the most intense which chemistry can produce; many substances formerly deemed infusible, being readily melted when exposed to this flame. An arrangement by which the two gases can be burned together without danger is called an *oxy-hydrogen blowpipe.* A simple arrangement of this kind may be readily understood from what has been said on the subject of the gasometer. One gasometer must be filled with oxygen, another with hydrogen, and the two so arranged that the escape gas pipes from both vessels may stand at an equal height and a little inclined to each other. Then on opening the proper cocks in the two, a current of gas will escape from each, which being inflamed together or being allowed to pass through the flame of a spirit lamp, will produce a heat so great as to melt a wire of platinum. Several contrivances may be employed to prevent any danger of explosion which might arise from the inflammation of a mixture of the two gases. A direct mixture of the gases before combustion would be perfectly safe by causing them to pass through Hemming's safety tube, a tube filled compactly and entirely with fine cylinders of wire, so that the gas must pass through the exceedingly fine tubes formed by the interspaces between the cylinders. Gurney's apparatus of safety may also be used.

4. *Apparatus for Combining Solid and Liquid Elements.*

As has already been remarked, there are only two elementary bodies which are liquid at ordinary temperatures; these are mercury and bromine. By far the greater number are solid. With respect to the latter we may say in general that one solid element does not combine with another. The condition of aggregation of bodies that are to combine together must be liquid or gaseous, a condition to which solids must be brought. Consequently we may consider the combinations of liquids and solids under one head, provided the solids be supposed to be rendered liquid by heat. Setting aside the gases, we have as non-metallic elements, boron, bromine, iodine,

carbon, phosphorus, sulphur, selenium, and silicium ; all the rest are metals. As far as any brief generalities can be made respecting the combinations of these simple substances, we may say that almost all the non-metallic elements combine in definite proportions with the metallic when brought together in a liquid state, while the non-metallic bodies, as well as the metals, either come together in any proportion, or else do not unite directly into a homogeneous whole. The instruments in which experiments of the kind are conducted, are retorts (*pl.* 30, *fig.* 25, and 26), matrasses (*figs.* 27, 28, 29), and crucibles (*figs.* 30, 32, and *pl.* 31, *fig.* 57), the application of all which has already been explained.

IV. Chemical Synthesis and Analysis. The Apparatus Required.

It has already been remarked that simple bodies do not often combine with compound, but compound unite with compound just as simple with simple. In by far the most cases we have in chemistry to deal with the combinations of compound bodies, and in chemical analysis we obtain two binary compounds as the result, as for instance a combination of oxygen and a metal on the one hand, and of oxygen and a non-metallic body on the other. The compounds of oxygen with the non-metallic bodies, sulphur, carbon, nitrogen, are generally acids ; the combinations of oxygen with metals are rarely acids, and exhibit in most cases a great tendency to unite with acids to form a salt. Potash, for instance, consists of carbonic acid and oxyde of potassium or pure potassa ; the former being composed of carbon and oxygen, the latter of oxygen and potassium. This potassa has so great a tendency to combine with carbonic acid as to seize hold of it whenever the two come into contact, to form the carbonate of potassa. These oxydes which stand in such a relation to acids are called *bases*, the compound itself is a *salt*. The tendency of one base to combine with two or more different acids is very different, this difference being indicated by the terms greater or less *chemical affinity*. It is hence readily intelligible that an acid which has a greater affinity for one base than another, may take the former from a combination which it may already have formed. On this principle depends the development of carbonic acid gas in the generating apparatus (*pl.* 31, *fig.* 46), which at the same time constitutes a very simple gasometer. In the glass cylinder A is placed a second cylinder, B, whose superior opening is fastened to the cover of AA, and, connected with a pipe provided with a cock, may be closed or opened by means of a cock at *a*, seen also in *fig.* 45. The wire C is suspended from a small hook in the tube, and carried beneath the bottom D, which is thus suspended a little above the lower end of B. By placing pieces of carbonate of lime (limestone, marble, or chalk) in the bottom D, and filling the cylinder A about half full of dilute sulphuric acid, the liquid will rise in A as soon as this is set in B. On opening the cock *a*, the dilute acid will rise still higher in B, driving out the inclosed air and covering the carbonate of lime. As sulphuric acid has a greater affinity for lime (oxyde of calcium)

than is possessed by carbonic acid, the latter will be displaced by the former, and will be liberated in the form of carbonic acid gas, the sulphuric acid combining with the lime to form a sulphate of lime. The evolution of the carbonic acid gas will depress the liquid in B, causing it to rise in A, and finally this depression will be so great as to leave the lime uncovered by the dilute acid. Further evolution of gas will then stop until the cock *a* is opened for the escape of carbonic acid gas, this escape being facilitated by the pressure of the liquid in A. As the gas escapes, the liquid is again enabled to attack the carbonate of lime, and to generate fresh gas, as before. This apparatus thus serves an excellent purpose in enabling us to keep constantly on hand a small quantity of this and some other gases, as hydrogen, for immediate use.

An apparatus by means of which nitric acid may be manufactured on a large scale is represented in *pl.* 31, *fig.* 55. It consists principally of a furnace of peculiar construction, called a *galley furnace*, the general relation of whose parts is shown by the figure. AA is the masonry inclosing the inner furnace space, D the chimney, F and E the fuel and ash-doors. BB indicates a series of cups in which glass retorts, as CB, are set. The retorts are filled half full of nitrate of potassa or saltpetre, and sulphuric acid poured in through a tube reaching nearly to the bottom of the retort. All the cups being provided with retorts properly prepared, and these provided with properly cooled receivers, heat is applied to the whole row by means of a single fire. As soon as the mixture in the retorts is raised to a certain heat, the sulphuric acid takes the potassa from the nitric acid, forming sulphate of potassa, and leaving the nitric acid free to escape into the receivers, there to be condensed.

An illustration of an entirely different method of separating one substance from another is seen in the ordinary assaying of silver and gold. If, for example, it be desired to ascertain how great an amount of silver is contained in any object, as a coin, some grains of the object are placed with a certain quantity of lead in a cupel (*fig.* 43) composed of bone earth and ashes. In mints and silver mines, where such operations occur daily, several such cupels are placed in a clay muffle (*fig.* 44). This muffle is then set in the opening, A, of the muffle furnace (*fig.* 42), and surrounded by red hot coals. In the glowing current of air within the muffle, the lead and copper (if copper compose the alloy) are oxydized, one portion of the oxyde of lead escaping in vapor, the rest, however, melting with the copper, and being absorbed by the cupel. The silver remains pure in the form of a round granule, which is weighed, and the amount of weight compared with that ascertained before the operation.

Having thus mentioned the principal generalities, with respect to the combinations of simple and compound bodies, we shall pass to the consideration of some more complex chemical operations. Thus, supposing it be required to obtain the metal aluminum from clay, which is its oxyde, we shall not be able to procure this directly from the clay itself. Nevertheless, we may replace the oxygen of the alumina by chlorine, and then we may abstract the chlorine by some metal, as potassium, which has

for chlorine a greater affinity than is exhibited by aluminum: this metal will thus be left separate, and resembling iron in general appearance. First of all, then, to replace the oxygen of the alumina by chlorine. For this, as well as many other purposes, we employ the apparatus represented in *pl.* 31, *fig.* 10, where A indicates a small furnace on which the matrass B is heated. In this is placed a mixture of powdered oxyde of manganese and hydrochloric acid, which, when heated, will generate chlorine for some hours: *c* is a safety-tube to prevent the bursting of the matrass by any obstruction in the tube *ee*. The chlorine developed passes through the glass tube, *d*, into the cylinder C, half filled with water, in which it deposits the impurities brought from B, and thus purified goes into the porcelain tube, *ee*. Into this tube have previously been introduced small cylindrical pieces of alumina, prepared by mixing with a solution of sugar or paste, and baking in a covered crucible until the sugar or paste is completely carbonized. The furnace, D, which, after being filled with coal, and fired up, is covered with its top, E, is intended to bring the alumina in the tube to a red heat. At this temperature the former affinities are suspended, and the oxygen of the alumina combines with the carbon of the carbonized sugar, forming carbonic acid; the aluminum being left in a metallic condition, is immediately seized by the chlorine. The chloride of the aluminum being liquid at a red heat, flows into the cooled receiver, *f*, attached to the end of the porcelain tube, *ee;* the gaseous carbonic acid likewise escapes through the tube *g*.

V. Chemical Examination of Organized Bodies, and the Apparatus Necessary for this Purpose.

The material forming the bodies of plants and animals is known as organized or organic, in contradistinction to the inorganic matter found in the mineral kingdom. Excepting the hard parts of the animal, as the bones, teeth, &c., and the ashes of the plant, which latter form a very slight percentage of its mass, the principal part of the animal body consists of but four elements: nitrogen, oxygen, carbon, and hydrogen; and of the vegetable, but three: oxygen, carbon, and hydrogen. The method of manipulation by means of which we may ascertain the amount of the individual elements in an animal or vegetable body, will be briefly described, and may serve as an example of the complicated and laborious investigations necessary for the purpose. Let the problem be, carefully to ascertain the proportions in which the four elements enter into a portion of animal matter, or the three into a part of a plant. The first requisite in solving this problem is a very accurate weighing of the amount of the substance to be subjected to analysis. All substances, however, in contact with the air, absorb a certain amount of watery vapor through their pores, which necessarily requires a careful drying of the body as an absolutely necessary preliminary to this weighing, else we should be in error by the weight of the water contained, which would be dissipated in the course

of the operation. This removal of water is effected by means of the following forms of drying apparatus:

The Drying Apparatus with Sulphuric Acid. Pl. 31, *fig.* 15.

This consists of the receiver A, fitting air-tight on a plate like that of the air-pump, and of the capsule, B, placed beneath the receiver, and half filled with concentrated sulphuric acid. The object of the acid is to remove moisture from the inclosed air by reason of its great affinity for it. The substance to be dried is placed finely powdered in a porcelain capsule, upon a triangle of iron wire (*fig.* 12) resting on the dish containing the acid, and is then to be left for several days. The moisture of the body gradually exhales in the perfectly dry air, and the capsule loses in weight by the amount of the water exhaled and absorbed by the sulphuric acid. *Fig.* 17 shows a still more advantageous construction of this apparatus. B is a large glass vessel with a ground edge; D, the contained dish with the sulphuric acid; C, a wire frame upon which the capsule with the object to be dried is set; A is a ground-metal cover, closing air-tight on the edge of B, previously rubbed with tallow. In its centre is an aperture, likewise capable of being closed by a ground-cover, and through which small objects may be introduced into the apparatus. For such substances, however, as sugar, which are capable of experiencing a pretty high heat without decomposition, other apparatus of quicker operation may be employed. Such are the water-bath, the oil-bath, and the air-bath (*pl.* 31, *figs.* 16, 18, 19, 20, 21). First, the *water-bath* (*fig.* 16). A is a copper vessel, with a properly fitting cover, possessing two intersections to receive the two legs of the glass vessel (*fig.* 20) set in A, and containing the substance to be dried. To one leg is connected the chloride of calcium tube *c*, which is continued into a tube bent at right angles; to the other leg is likewise attached the chloride of calcium tube *b*. The former is fitted air-tight by means of cement in the cork of one opening of the Wolff apparatus B. The second opening, *e*, of the bottle contains a funnel tube, and in the third, *f*, is fixed a syphon. The kettle, A, is to be filled with water, so that the vessel (*fig.* 20) containing the substance to be dried may be completely covered, and the water brought to boil by means of the furnace C. At the same time a vessel filled with water is placed above the funnel-tube, *e*, from which water may be made continually to drop into the funnel. The water thus entering soon covers the bottom of the syphon tube, and drives the air from the bottle, B, into the chloride of calcium tube *c*, in which all the vapor contained in the air in B is retained. A stream of perfectly dry air then passes through the vessel containing the substance in question, and soon takes up all the moisture which may be there. The chloride of calcium tube *b* absorbs the water thus abstracted from the substance. By extracting the cork containing the funnel-tube, and starting a current of water from the syphon, the water in B may be removed, and the operation of furnishing a current of dry air again continued as before.

Other apparatus is at the command of the chemist for producing a current of perfectly dry air for such purposes. *Fig.* 22 shows at A a flask partly filled with sulphuric acid, connected by means of conducting tubes with the drying vessel and the aspirator B. The latter is a cylinder of sheet-copper or zinc, provided below with a cock, *b*, and above with a funnel-tube, *a*. This is filled entirely with water through the funnel-tube *a*, and the funnel then closed by means of a cork. On opening the cock *b*, the water will flow out of the cylinder B, since the air entering through the tube *d* ascends through the concentrated sulphuric acid into the vessel A, and is thus dried; it afterwards passes over the substance placed in *c*, to fill the space left vacant in the aspirator B by the withdrawal of the water.

The apparatus (*pl.* 31, *fig.* 23) is used in a similar manner, differing only in that the vessel of sulphuric acid is replaced by a chloride of calcium tube, *b*, in which the inhaled air is dried. Finally, in *fig.* 21, the aspirator is replaced by an air-pump. The body is placed in a small matrass, immersed in the kettle. From this there leads a chloride of calcium tube for drying the air left by the air-pump after extracting the watery vapor. In other particulars, the operation of this apparatus is similar to that already described. By means of these forms of apparatus we are enabled to dry a substance at the boiling point of water; other contrivances are necessary, however, when the heat required, and possible, is greater than 212° F. Thus sugar at 212° indeed loses all the water mechanically combined, but at a temperature of 329° F., it loses a definite proportion of chemically combined water, and the determination of this is of great importance with reference to the nature of this substance. For the purpose of exposing this and other bodies to a higher temperature, then, than that of boiling water, we make use of the oil bath (*fig.* 18), or the air bath (*fig.* 19.)

The *oil bath* (*fig.* 18) consists of a quadrangular box with double walls, about an inch apart. The intervals, *a*, *a*, *a*, *a*, between these walls, are filled with oil introduced through the aperture, *c*. In the opening, *b*, is set a thermometer, with its bulb dipping into the oil, so as to enable us to ascertain the temperature; the bottom of the box is heated by the furnace on which it is to be set. The substance placed in a capsule, is introduced into the space within the box, and the door A shut. By means of the thermometer, the heat may be so regulated, as not to exceed a certain temperature. Place, for example, a weighed vessel of sugar within this apparatus, and weigh it from time to time; we shall find that it decreases in weight for a while, and that after a time this weight remains stationary, the loss being not an arbitrary amount, but exactly proportioned to a given quantity of sugar.

The *air bath* (*fig.* 19), intended to answer the same purpose as the last, is still more convenient. A, is a cylinder of sheet copper, within which a ring, *c*, *c*, is laid. The upper part of this cylinder is closed by a copper cover provided with two openings. In one opening, *a*, is set a thermometer, and through the other the neck of a glass matrass of known weight is

passed, its bulb supported by the ring, *c*, *c*. Into this matrass the substance is introduced, which is to be dried at any temperature. The opening of the matrass must be closed by a cork through which passes a fine glass tube to be connected with a tube, *e*, filled with chloride of calcium. The cylinder, A, is heated by a subjacent lamp, and a definite temperature thereby communicated to the air surrounding the matrass in the cylinder. The conducting tube, *f*, is brought into communication with an air-pump, and while the matrass with its contents is heated in the air bath, the air-pump from time to time extracts the moisture-charged air. The air which would return into the matrass on opening the air-pump, must first pass through the chloride of calcium, and will be there dried before it can enter into B.

By means of the apparatus just described, we are enabled to separate the water from any body whether chemically or mechanically combined with it. All the water being thus removed from the body, suppose the problem to be, to determine its remaining components. If sugar be the substance in question, take a certain amount and dry it in one of the ways just described. Pure oxyde of copper is next to be well heated in a crucible (*pl.* 31, *fig.* 57), and the known weight of sugar mixed with it, after the covered crucible has been allowed to cool to 250–260° F. This mixture of oxyde of copper and sugar is to be introduced into a tube (*fig.* 29) from one half to two feet long, made of the most infusible glass, the lower end of which is drawn out into a fine closed point. As both the oxyde of copper and the sugar absorb fresh moisture during the mixture, this must first of all be again removed. This is done by the application of the air-pump (*fig.* 24). This pump, A, is made to communicate by a tube, B, with the chloride of calcium tube (*fig.* 25), this tube itself inserted air-tight by the help of a pierced cork, *a* (*fig.* 25), into the mouth of the tube (*fig.* 29), after it has been filled with the mixture of oxyde of copper and sugar. The tube, as shown in *fig.* 24, is placed in a box, E, E, and surrounded with sand previously heated to 250°. The heat of the sand is communicated to the tube, D, which contains the mixture, and the water previously absorbed becomes vaporized. By means of the air-pump, A, the air contained in D, and charged with vapor, is carried through the chloride of calcium tube, C, in which the vapor is retained. On opening the cock, *a*, of the air-pump, the air again enters the tube, D, perfectly dried by the chloride of calcium, and is charged afresh with moisture. In this way the mixture of the two substances in D becomes after a time perfectly dry. The tube, D, or the *combustion tube*, is now separated from the chloride of calcium tube, C, and laid in the combustion furnace (*fig.* 30). This is a box of sheet iron, about two to three feet long, and one half foot broad at the upper and open top, being somewhat narrower below. The bottom of this is seen in *fig.* 32, to be pierced transversely to permit the air to come in contact with the burning coals; there are also notched transverse partitions, upon the edges of which the combustion tube is to rest, as seen in *fig.* 31; in this figure the anterior wall of the furnace, AA, is supposed to be removed. In the opening, *b*, of the combustion tube, DD, is inserted by means of a

dry cork, a chloride of calcium tube, *a* (*pl.* 31, *fig.* 26), filled to *cc*, or else the simple chloride of calcium tube (*figs.* 27 and 28), as also *figs.* 30, 31. To this tube again is fixed the so called potash apparatus, F (*fig.* 30). This consists of a glass tube in which five bulbs are blown and arranged, as shown in the figure. The three bulbs lying in a row are filled with solution of potassa by dipping one end, *c* (*fig.* 39), into a vessel, H, containing solution of potassa, and sucking up the ley by means of the sucking tube, G, attached to the other end. When the potash apparatus is filled with ley, it is attached to the chloride of calcium tube, E (*fig.* 30), by a caoutchouc tube, *c*. Finally the combustion tube, D, is gradually surrounded entirely with burning coals, applied first anteriorly and then with great caution along the tube. The entire arrangement has the following end in view: The oxyde of copper with which the sugar has been mixed, gives off, as soon as it has been heated to redness in the combustion tube, its oxygen to the carbon and hydrogen of the sugar, forming with the former, carbonic acid, and with the latter, water. The oxygen naturally contained in the sugar likewise combines with the two other elements. The oxygen and hydrogen then of the sugar, together with the oxygen of the copper, all enter into combination, and are entirely converted into watery vapor and carbonic acid. Both of these substances converted into gas by the heat, pass over into the chloride of calcium tube, E. A great portion of the watery vapor readily condenses by communication with the air, and collects in the bulb *a;* the remainder is entirely abstracted by the chloride of calcium filling the apparatus to *c*, *c*, *fig.* 26. The carbonic acid enters into the potash apparatus, in which it is entirely absorbed. The combustion tube, D, and the chloride of calcium tube, E, still contain some carbonic acid which must also be brought into the potash apparatus. For this purpose the fine point of the combustion tube is broken off, and over the aperture is placed a glass tube, C (*fig.* 31), open at both ends, and sustained by a holder, B. The suction tube, G, or *fig.* 53, is applied to the potash apparatus, and a current of air drawn through the tube, C, into the combustion tube, DD, which gradually draws over into the potash apparatus the whole of the carbonic acid, there to be absorbed. The chloride of calcium tube, E, had been weighed before the operation; it is now again to be weighed, when the excess of weight will express the amount of water which was formed from the hydrogen of the sugar in its combustion with the oxyde of copper. The potash apparatus has likely been previously weighed, and its excess after the experiment will be the amount of carbonic acid formed from the carbon of sugar. The combining numbers of both water and carbonic acid are already known; in nine parts by weight, water contains one part of hydrogen and eight of oxygen. The amount of water ascertained, divided by nine, will give the amount of hydrogen contained in the given weight of sugar. Carbonic acid consists of three parts by weight of carbon and eight of oxygen; multiplying the amount of carbonic acid as ascertained, by the fraction $\frac{3}{11}$, we shall have the amount of carbon contained in the sugar examined. Finally, by adding together these two amounts thus found, and subtracting from the known weight of the dried

sugar we shall obtain indirectly the amount of oxygen in the sugar, thus completing our knowledge of its components. However complicated the preceding manipulations may appear, nevertheless, by properly observing all the conditions necessary, very accurate results may be obtained.

A special mode of treatment is required in the case of certain liquid and at the same time volatile organic matters, as alcohol, which cannot be mixed with oxyde of copper without loss. These are inclosed in little glass bulbs drawn out into a long tail, and one or two of these bulbs filled with the substance in question are laid in the combustion tube, as shown in *pl.* 31, *fig.* 27. The bulbs are covered with oxyde of copper, the tails being broken off. The rest of the operation is as in the case of dry organic matter. To the question which is answered by the analysis of a volatile organic body, there is almost always united another with respect to the specific gravity of its vapor, so that the determination of this always accompanies the analysis. For this purpose we make use of a balloon (*fig.* 41) provided with a long tube bent nearly at right angles. After weighing this with the inclosed air we pour in enough of the liquid, the density of whose vapor is to be ascertained, for the volume of the vapor generated to exceed the volume of the balloon. This is then fastened by wire to the post, A (*fig.* 40), carried by the holder, D, and the balloon immersed in the oil bath, B, whose temperature is observed by means of the thermometer, *a*. The oil bath is heated by the furnace, C, to above the boiling point of the liquid in question, and at the moment when all the liquid in the balloon has been converted into vapor, the point of the tube is melted together by a blowpipe. The balloon is then allowed to cool and again weighed. Its present weight is that of the balloon and the contained vapor, which has driven out all the air; the former weight was that of the balloon and the contained air. The volume of the balloon is determined by filling with distilled water and weighing. We can readily ascertain the volume occupied by a known weight of distilled water, and consequently the volume of our balloon, and hence also the weight of the included air of the empty balloon. Thus we get the weight of the vapor which occupies the same space as the air of the balloon.

There are numerous substances which do not completely burn with oxyde of copper alone. For such we can make use of a current of oxygen which may be passed over the oxyde of copper during the combustion. As the whole process and its accompaniments are much as we have already described, we shall here only mention the apparatus especially necessary. In *pl.* 31, *fig.* 33, AA represents a gasometer filled with oxygen gas. Next to it is a gasometer filled with air, communicating with the tube, C, through a tube, *c*, so that by opening the proper cocks, either oxygen or air may be allowed to pass through the apparatus. The tube, C, carries the gas into the bottle, D, containing sulphuric acid, and from this into the potash apparatus; both these vessels, with their contents, are intended to free the oxygen and the air from the watery vapor which may have been dissolved in them. The combustion tube, F, which contains the substance to be burned, mixed with oxyde of copper as before, is heated by means of a brass spirit lamp, PP. Enough spirit is poured into the cup, M, to fill the

lamp, PP, to a proper height, the communication between the two being through the tube, NN. A glass bottle is inverted over the cup, M, so as to permit a glass tube passing through the stopper, L, to dip somewhat into the spirit in M. As soon as the level of the spirit in the cup sinks, that in the bottle flows out, and in this way its level in the lamp, PP, remains the same. The substance is burned as formerly, and the only difference between this and the preceding method consists in the passage of a current of oxygen over the oxyde of copper. In this is involved the apparatus, I, placed next to the potash apparatus. It consists of an U-shaped tube filled with pieces of potassa. This, as well as the chloride of calcium tube, and the potash apparatus, is weighed, and its object is to take up a certain amount of water carried off by the dry oxygen in passing through the potash apparatus. Furthermore, since all this apparatus had been weighed before the experiment when partly filled with air, and since the space occupied by the air is partly filled by oxygen (one tenth heavier than air) after the combustion, this gas must be again replaced by air for the final weighing. This is done by means of the second gasometer, after the cock of the first has been closed.

Substances which, like most that belong to the animal kingdom, contain nitrogen in addition to the rest, require this new element to be determined. After its amount of carbon has been ascertained, a second mixture of the substance with oxyde of copper is brought into a combustion tube (*pl.* 31, *fig.* 34). Only a part of the substance introduced into the combustion tube is burned at first, the resulting gaseous products being used to expel the air occupying the tube. As soon as this has been driven out, the remainder of the substance is burned, and the gaseous mixture furnished by the body together with the oxyde of copper, is collected. This is done by means of the tube, *a*, which carries the mixture into a graduated cylinder, C, filled with mercury. The cylinder being filled about one third with the gas, and the amount measured by the graduation on the tube, a sufficient quantity of solution of potash is taken up in the pipette (*fig.* 35), and thus introduced into the cylinder, C. The object of this is to remove the carbonic acid from the gaseous mixture, which consists of carbonic acid and nitrogen, after the condensation of the major portion of the watery vapor; in this way we are enabled to ascertain the relation of volume between these two gases. By calculation we can extend this ratio to the relative amount by weight of the two gases, and as the carbon has already been determined by a preceding analysis, we shall have the data necessary to determine the quantity of nitrogen corresponding to the carbon already found.

Another method of determining the nitrogen consists in directly burning a weighed amount of the substance to be investigated, and after procuring the entire amount of the contained nitrogen, to measure it. For this purpose we may use the apparatus shown in *fig.* 36. The combustion is conducted in the usual manner in the combustion tube *ab*, which is filled from *a* to *b* with a mixture of the substance with oxyde of copper, and from *b* to *c* with copper turnings. The solution of potassa is placed in the vessel *f*, which incloses the graduated tube *g*, also filled with the solution. As all the

products of combustion of a substance composed of carbon, hydrogen, nitrogen, and oxygen, can only consist of water, carbonic acid, and nitrogen, there remains in the graduated tube *g*, after all the carbonic acid has been abstracted by the potassa, only the nitrogen, which may then be measured. In this experiment, it is true that the air has passed over from the combustion tube into the graduated tube *g*, but since the volume has been determined no error will arise from this mixture with the nitrogen. The tube *a* reaches with its bent leg nearly to the cover of the graduated cylinder *g*, and as soon as the combustion tube, *ab*, is cooled, as much of its gaseous contents passes from the cylinder *g* into the combustion tube as is necessary to fill it. The tube *g* being divided into cubic inches, or cubic centimetres, we can readily calculate the weight of the contained nitrogen, knowing the weight of a cubic inch or centimetre.

The volume of nitrogen may be more accurately determined than in the preceding method by means of the apparatus (*pl.* 31, *fig.* 37[a]). The combustion tube, *a*, *b*, *c*, *d*, is filled from its posterior extremity, *a* to *b*, with carbonate of lead, from *b* to *c* with the mixture of oxyde of copper and the substance to be burned, and from *c* to *d* with copper turnings. The first half of the carbonate of lead is heated, by which means its carbonic acid is liberated, and the air thereby expelled from the whole series of tubes. To assist in the expulsion of air from the tube, the air-pump A, with the tube B, is applied to the intermediate joint of brass, provided with the cock *f*, this joint carrying at one side the vertical glass tube *h*, a little over twenty-eight inches in length. The lower end of this tube dips into the mercurial trough C. The cock, *f*, is to be opened and the air pumped out from the whole apparatus, by which means the mercury ascends to a height of nearly twenty-eight inches in the tube *h*. The cock, *f*, is now to be closed, and the carbonate of lead heated red hot, until the carbonic acid liberated depresses the mercury in *h* again into the trough, and escapes from the mercury in bubbles. The cock, *f*, is then again opened, and the previous operations repeated, until all the air has been expelled by means of the carbonic acid gas and the air-pump. The cock is now to be closed, and the bent lower extremity of the tube, *h*, brought under the cylinder D, filled with mercury, this being held erect by the holder E; the substance also is to be burned by means of coals surrounding the combustion tube, *a*, *b*, *c*, *d*. As soon as a considerable quantity of gas, consisting of watery vapor, carbonic acid, and nitrogen, has accumulated, a sufficient amount of solution of potassa is introduced into the cylinder D by means of a pipette; this solution will take up both the water and the carbonic acid, leaving the nitrogen, which, however, will still contain a little vapor of water. Afterwards, to measure the amount of nitrogen, we must introduce a shallow dish under the opening of the cylinder, and remove it with the cylinder from the trough, the mouth of the cylinder still remaining closed by the mercury filling the dish. In this way the cylinder is brought into a high vessel (*fig.* 38), A, filled with water, and the dish removed. The mercury will fall to the bottom, and the gas remain included by the water. The graduated cylinder is depressed in the water until the surface of the water inside stands just at

the same height as that in the vessel A; the number of cubic inches or centimetres contained is then to be read off.

All these methods for nitrogen depend upon measurements of gases, which can never be so accurate as weighing, as they are exposed to many more errors of observation, since, besides the direct volume occupied, we should have reference to the height of the barometer and thermometer. The following method furnishes the nitrogen in a form in which it may be weighed: let *fig.* 37^b represent the combustion furnace with the contained combustion tube, A. Into this tube is introduced the substance to be burned, mixed, however, with carbonate of soda instead of oxyde of copper. On heating the mixture the organic matter is burned, at the expense of the water combined chemically with the soda, this water giving off its oxygen to the carbon of the organic body, and its hydrogen to its nitrogen. Ammonia results from this latter combination, which is received in the apparatus B, inserted in the combustion tube, A, by a cork, and filled with hydrochloric acid. A salt (chloride of ammonium or sal-ammoniac) is produced by the combination of the ammonia and hydrochloric acid, which is not volatile at the boiling point of hydrochloric acid, so that after pouring out the liquid from B into a capsule, the sal-ammoniac may be obtained separate by evaporation. This is then dissolved in dilute alcohol, and chloride of platinum added, which, combining with the chloride of ammonium, forms a double salt, the double chloride of platinum and ammonium, which is insoluble in alcohol. This double salt, after drying, is weighed, and from this weight the weight of the contained nitrogen may readily be determined.

Nitrogenous substances are generally of animal origin, and often contain sulphur and phosphorus in their composition. To obtain these substances in a form in which they may be weighed, they must be converted into acids; for which purpose we may employ the apparatus, *pl.* 31, *fig.* 65. The substance whose proportion of phosphorus is to be ascertained, must be mixed with soda and saltpetre, and placed in a combustion tube, there to be burned. The carbonic acid formed during combustion escapes through the anterior open end of the tube, and in the reliquiæ the sulphur will occur as sulphuric, and the phosphorus as phosphoric acid, which may then be separated.

VI. Mechanical Separation, and the Apparatus Necessary.

Use is often made in chemistry of methods which do not strictly belong to the operations of chemical analysis. Thus, suppose the oxyde of iron to have been precipitated from a solution of iron, and suppose it be necessary to weigh the former: the first condition necessary will be to separate the oxyde from the liquid from which it had been precipitated, and from the substances used in causing the precipitation. The liquid is first poured on a paper filter laid on the funnel, A (*pl.* 31, *fig.* 50), and allowed to run off into a tumbler, C, placed beneath, the precipitate remaining on the filter.

The latter, however, contains a part of the liquid, as also of the substance causing the precipitation, both of which must be removed. This can, in most cases, only be done by long continued washing in distilled water. An arrangement is therefore needed which shall allow an uninterrupted current of pure water to flow on the precipitate, so as to wash entirely away from it anything soluble in water. For this purpose, we make use of the two-branched tube (*pl.* 31, *fig.* 47), which is inserted into the cork of a bottle filled with water, as seen in *fig.* 48, B. The tube (*fig.* 47) is immersed up to about *ab* in the liquid in the funnel, A (*fig.* 50). The two slides, *d*, *d*, can be fixed on the vertical rod, D, at any height, so that the washing bottle, B, may have any appropriate position. When the level of the liquid in the funnel A has sunk so far that the tube (*fig.* 47) is immersed only to *cd*, the column of water, *abcd*, higher by *ac* or *bd*, has a tendency to settle at a height equal to that of the liquid in the funnel A, the atmosphere pressing on the column through the tube *e*. It therefore flies out, and in the space thus reached there enters a bubble of air through the tube *e*. Now as air is much lighter than water, this bubble immediately ascends into the tube, *f*, filled with water, and enters into B (*figs.* 48, 49, and 50). By this the water in the funnel A again rises to the height *ab*, this action being continued uninterruptedly. When, however, the water level in the funnel is the same with that within the tube *ab*, the action of the tube (*fig.* 47) ceases spontaneously; for as soon as the column *abcd* no longer flows out, the remaining column in the tube *f* is supported by the pressure of the atmosphere acting through the tube *e*, like the mercury of a barometer. The adhesion of the water to the conical part of the tube likewise facilitates the action of the tube, so that the column *abcd* stands generally a little higher than the surface of the water in the funnel A. This two-legged tube may easily be replaced by two tubes set close together in a cork, the action being the same in both arrangements. An arrangement of this kind is intelligible from an examination of *fig.* 49.

A simple filtering apparatus is shown by *figs.* 51 and 52. A represents the stand, B a tumbler into which the liquid is filtered, C the funnel, D differently arranged slides, which, by means of screws, can be fixed at any elevation on the vertical rod of the stand A.

In washing the precipitate, instead of the double-legged tube of the preceding apparatus, we may make use of the *washing bottle*, as shown in *pl.* 30, *fig.* 49, and *pl.* 31, *fig.* 54. In the first of these we blow into the bottle, half full of water, thereby compressing the contained air. On quickly inverting the bottle the pressure of the air forces out the water in a fine stream from the pointed glass tube which had been inserted into the aperture of the bottle by means of a cork. The water escapes, therefore, in a jet, and by directing this upon the filter the precipitate is quickly stirred up and well washed. The second apparatus (*fig.* 54) serves the same purpose, only the air is blown in through the tube *b*, and the water driven out through the tube *a*, which reaches nearly to the bottom of the bottle half full of water.

Funnels (*pl.* 30, *fig.* 46). The filtering funnels used in chemical

operations are generally constructed of glass. Their broad portion is so fixed as that two opposite lines, drawn from the border to the apex of the cone portion, shall form nearly a right angle with each other. In the earlier chemical manipulations special funnels were employed, such as the one in *pl.* 30, *fig.* 48.

Separating Funnels (*pl.* 30, *figs.* 42 and 47) are instruments for separating two liquids which do not mix, and which possess different specific gravities, such as oil and water. The two liquids are poured through the upper opening into the vessel, and the latter closed air-tight by a well fitting stopper. The whole must be allowed to rest quietly until the liquids have separated into two layers. The lower aperture is then to be opened and the inferior layer permitted to escape. On closing the superior aperture with the finger the upper layer will remain in the vessel.

Florence Flasks (*pl.* 30, *figs.* 51 and 54). The essential idea of these flasks consists in such an arrangement that in a tube open above and below, or in a flask itself, liquids may continually flow to and fro without the level of the liquid in the tube or flask sensibly changing. Flasks of this kind are used to separate a small amount of a specifically lighter body from a great quantity of a specifically heavier one. Thus, let water distilled over plants containing volatile oils flow into the tube of the flask while the lower end of the tube remains closed by the water in the flask; then the oil will constantly remain floating within the tube, the water itself entering the flask until it flows out of a lateral opening. In a similar way in the flask (*fig.* 51) we may collect such an oil in the neck, since the water can escape through the tube B.

VII. Chemico-Physical Instruments.

Instruments indispensable to the chemist, and which at the same time are used in Physics, are the barometer, the thermometer, and an accurate balance or pair of scales. The former instrument is sufficiently well known. As the thermometer is intended to determine the temperatures of very different substances, boiling acids, for instance, its scale must be marked directly on the glass, or else be inclosed within a glass tube. The various forms in *pl.* 30, *figs.* 37–41, are given for the purpose of introducing them into the interior of other apparatus, or in order to a more ready support.

Pl. 30, *fig.* 69, presents the most usual form of the ordinary *Chemical Balance*. The cylinder, EA, is a brass stand carrying the balance. At *l* is an eccentric disk, on turning which by the button *k*, the knife-edge on which the beam of the balance rests when in use, may be raised to prevent any injury to the delicacy of its edge. Just above *l* there is a small plate of ivory, graduated to degrees, for noting the movements of the tongue E. The beam of the balance is divided into ten divisions for the sake of weighing by tenths of small weights, constructed of platinum wire, and suspended from the divisions of the beam. The suspension arrangement of

the scale-pans and that of the beam is shown more fully in the succeeding figures.

Pl. 30, *fig.* 70, represents the method of hanging the balance beam, which in the figure appears cut off at each end, so that only the two central pieces, BB, connected by the central annular body, are visible. *a* is a triangular prism of steel, the edge of whose lower acute angle rests on a plate of agate, *b*. It passes at right angles through the middle of the beam, supported at both extremities by agate plates. Both of these are carefully laid in the same plane. *ee* is a brass frame inclosing the body on which the agate plate rests. This frame can be raised or depressed by means of a pin connected with the excentric disk, *el*. When this frame is raised, it catches the very extremities of the knife edge in two opposite notches, and raises it with the beam from the agate plate. The figure represents only the anterior arrangement of the knife edge and agate plate, the posterior being precisely similar. When the knife edge is raised by the frame, *ee*, the two pins, *hh*, of an arm, *gg*, firmly connected with the frame, *ee*, catch at the same time under the scale beam, and support it still more.

Pl. 30, *fig.* 71, represents the suspension apparatus of the pans. The plate, *m*, is screwed to the end of the beam, B. At *o*, the pan is suspended by means of a hook in the ring of the stirrup, into which the plate, *m*, is continued. By means of the screw, *n*, the length of the beam from the knife edge to the point of the suspension may be made perfectly equal for both arms.

Pl. 30, *fig.* 72, is another arrangement for suspending the pans, after Hoss. The most essential part of this arrangement is a steel plate (*fig.* 73), provided at one end with a knife edge. This knife edge is divided into two parts by a small intersection, widening below. The hook *r* (*fig.* 72) carries in its middle a fine plate of metal, which, fitting in the intersection of the knife edge, renders a lateral displacement of the hook impossible. The parallelism of the knife edges or the equal length of the arms may be regulated by screws attached at *o*, *p*, and *n*.

VIII. Miscellaneous Apparatus for Special Investigations.

Davy's Safety Lamp (*pl.* 31, *fig.* 59). In mines of different kinds, in coal mines especially, a certain gas, carburetted hydrogen, often forms in considerable quantity, and this, when mixed with air, becomes highly explosive. Inflamed as it frequently is by contact with the light used by the miner, it produces the most disastrous consequences to life and property. Such accidents are prevented by the proper use of the safety lamp. The right hand figure exhibits a section of the apparatus, which consists of a frame, at the lower part of which is placed a lamp, the frame itself being completely inclosed by a wire cylinder of very fine copper gauze. On introducing this lamp into an explosive mixture, the gas penetrating the interstices of the gauze, within the inclosed space, may indeed be set on fire, but the flame

cannot be communicated to the outside, owing to the rapid reduction of temperature experienced by contact with the metal.

Davy's Apparatus for Investigating the Earths (shown in *pl.* 30, *fig.* 61). is intended specially for examining the amount of gas generated from a calcareous earth under the influence of an acid. D is a retort containing the earth, E a vessel for receiving the acid, provided beneath with a stop-cock ; *b* is a connecting tube, to the lower end of which a contracted bladder is fastened ; B is a retort filled with water, and A a graduated measure. After the earth has been introduced into D, the cock at E opened, and the acid let in on the earth, the liberated gas passes through the tube, *b*, into the bladder, *c*, expands this and thereby displaces an equal amount of water from B, which passing over to A, indicates by its level at *a*, the volume of gas introduced.

The Wolff Apparatus (*pl.* 30, *figs.* 56 and 57) is intended to be used for saturating liquids with soluble gases. Thus, suppose it be desired to prepare a saturated solution of chlorine in water, the generating apparatus (*fig.* 56) is applied to the tube, C, and the bottles, A and B, filled one third with water. On allowing the gas to enter through C, it gradually displaces all the air in the apparatus, and the water in A gradually purifies the gas of improper admixtures. The gas then passing over to the bottom of the water in B, rises through the water and is in a great measure dissolved, the water becoming gradually saturated. The excess of gas, or that which has not been dissolved, may be made to pass over into a third flask, and thence to a fourth, &c. D and F (in *fig.* 56) are safety tubes, through which the expansive force of the gas may be spent in driving out the water in the bottles whenever any obstruction occurs, instead of bursting the vessel. *Fig.* 57 exhibits the apparatus as connected with an apparatus for generating the gas.

Apparatus for making anhydrous hydrocyanic or prussic acid (*pl.* 30, *fig.* 62). In the cylinder, *b*, the hydrochloric acid gas is generated, which enters through the tube, *a*, into the porcelain tube, D, in which cyanide of mercury has been laid, and where, by the decomposition of these two compounds, produced by the heat of the coal fire, G, prussic acid is generated. In the hollow, E, of the tubular extension of D, are placed pieces of chloride of calcium and chalk, kept cool by the snow with which the vessel, ABC, is filled for the purpose of condensing any watery vapor which might form, &c. The hydrocyanic acid vapor enters the tube, F, which is surrounded by an artificial freezing mixture, as of salt, snow, and dilute sulphuric aid ; by this means the volatile acid is condensed.

Pharmaceutical Steam Apparatus. *Pl.* 30, *fig.* 13, represents a quite recent form of steam apparatus very convenient for pharmaceutical purposes. The dotted box, A, is the steam boiler. Beneath it is the fire space with its door, *a*, and beneath this, again, the ash-hole to which the door, *b*, leads. From the upper plate, F, projects the matrass or alembic, C, heated by the steam of the vessel, A ; G is the extremity of its neck through which the products of distillation pass. Next to this matrass are several openings on the plate into which are set the tin boxes, *c*, *c'*, *c''*, capable of being

removed by means of their handles. They are closed by a well fitting cover, and are used for making extracts, infusions, &c., of roots, stems, leaves, &c., placed in them. The steam ascends through a tube, *f*, into a second and smaller vessel, D, fitted with a cover, in which are inserted arrangements, *g*, *g'*, similar to those last described, for boiling or evaporating. The vapor which collects in this boiler, and passes through the tube, *h*, is almost entirely condensed to water, and accumulates in the vessel, E, in which then there is always an abundant supply of distilled water so necessary for many purposes. The doors, *m*, *m'*, *m''*, lead to spaces which may be heated by steam, and if necessary, by a fire made in *k*, *l*. We may thus, as is readily intelligible from the figure, boil, distil, evaporate, and dry all at once by a single heating of the boiler.

Fig. 14 is a similar arrangement also explicable by the preceding description. D and C are steam boilers into which project the pots, *k*, *k*, *k*, and the vessels, L, M, Z. The fire space with its door is seen at B. F is the distillatory apparatus projecting by about half the length of its neck into the neck of G, in which the vapors are condensed. I is a tube from the boiler, which also goes into the cooler, H, and furnishes an uninterrupted supply of distilled water. The door, E, leads to the drying press, also heated by steam.

Fig. 15 represents the ground-plan of the fire space of the preceding apparatus. *Fig.* 16 is a copper vessel in the upper part of which is suspended a pan, and heated by being set in one of the openings in the upper plate of the boiler.

Fig. 17 is the porcelain pan or saucer setting in *fig.* 16. *Fig.* 18, the ring set on the copper vessel and carrying the porcelain pan. *Fig.* 19, a plate with four apertures, into which pots such as are seen at *k*, *k*, *k*, in *fig.* 14, may be set. This plate can be laid on an opening in the copper plate of the boiler, and the contents of the pots thus heated. *Fig.* 21 represents a single one of these pots.

Pharmaceutical Extract Press. *Pl.* 30, *fig.* 65, represents the hydrostatic press as given by Real. Its object is to express the juice of plants under great pressure. For this purpose such substances are introduced into the space, A, on a sieve bottom over B, and the entire space, as well as the tube, C, filled with water. This tube is made several stories high and leads to some convenient part of the house. As soon as the column of water in C is brought into communication with the water in the cylinder, A, the column of water exerts a pressure corresponding to its height, on the substances placed in A, which are therefore more completely penetrated by water. The extract obtained is removed from beneath, after a proper time, by opening the cock, *d*.

Pl. 30, *fig.* 66, is essentially the same apparatus, and is intelligible by means of the same description as in the preceding paragraph, with the variation only that a column of mercury is used instead of water. The apparatus is first filled from D, with water, the cock, *e*, closed, and the tube, E, filled with mercury.

Fig. 67 exhibits a press for the same purpose after Rommershausen.

The substance from which the extract is to be made, must be introduced into the cylinder, A, on a sieve bottom, *d*, covered by a cloth, and pressed upon by a second superimposed perforated bottom, *e*, lightly pressed against the substance during the operation by screws passing through the cover: this is attached by clamps. The liquid by means of which the extract is to be made is poured upon the stamper, GE, by means of a measure (*fig.* 50), graduated on the inside. On raising the piston, E, this passes through the valve, *e*, into the lower space of the cylinder, and on depressing the piston, through the valve, *a*, into the canal, *b*, presses against the sieve bottom, *b*, and the substance between *d* and *e*, and collects above *e*, in the space B, from which it can be readily removed.

Fig. 68 is also an extract press, in which a pressure is exerted by means of the piston, DE, on the liquid in the space G, which covers the substance whose extract is to be obtained. B is a filtering apparatus. By opening the stopper, *b*, the liquid is introduced. It is removed by turning the cock *c*.

Pl. 30, *fig.* 63. An apparatus for producing small quantities of illuminating gas from various substances. The substances to be exposed to a dry distillation are placed in *d*. The gas passes through the connecting tube, C, into the receiver, *b*, which may be removed at pleasure, or from which the gas may be let off by means of a cock, *e*, and the tube *a*, or else may be burned by means of a burner set on *a*.

Pl. 30, *fig.* 64. *Argand's Oil Lamp*, for drying precipitates or filters. A movable arm slides on the stand A, and can be fixed by means of a screw. This arm carries the furnace, C. B is an Argand lamp. A boiler is placed in C, having a lateral escape pipe for letting off the steam. D is a glass vessel with a rim, which rests on the edge of the boiler and closes it. In this vessel the filter to be dried is laid, and fixed by means of the piece E. When the water in the boiler has been made to boil by the lamp, the inside of the glass vessel becomes heated, and the filter dries rapidly.

IX. The Chemical Laboratory at Giessen.

The first requisite to a satisfactory pursuit of chemistry, is, in every instance, as well regulated and complete a laboratory as possible. No science is so dependent on experiment as chemistry, every fact requiring ocular demonstration. For this reason every facility rendered to chemical operations is a clear gain. Private laboratories are no guide to the general investigator, each individual arranging his own premises according to his particular line of study. Universities, however, and technical establishments, should not be without complete laboratories, in which all imaginable operations may be carried on. We have therefore concluded to present to our readers an idea of a chemical laboratory, the first one established in Europe on a large scale, and one in which, under the direction of its distinguished founder, Liebig, a host of young chemists have been trained for years past, and in which some of the most important contributions to

chemical science have been prepared. *Pl.* 30, *fig.* 1, exhibits a ground-plan of this great laboratory of the University of Giessen, and under it is a perspective view of part of the analytical laboratory. The different portions of *fig.* 1 indicate the following parts of the building:

A, lecture room; B, analytical laboratory; C, pharmaceutical laboratory; D, instruments and library room; E, weighing room; G, steps to the second story; H, privy; KK, laboratory and cabinet of the director; L, room for preserving preparations; M, store room; N, washing room; O, room for the servants in the laboratory; P, old laboratory; Q, ante-chamber; R, yard and garden; *a*, black-board, capable of being raised or lowered; *b*, fireplace used in the lectures; *c*, iron door; *d*, closed fireplaces; *e*, table for nitrogen operations; *f*, door between laboratory and lecture room; *g*, potassium furnace; *h*, sand bath; *i*, work table with shelves; *k*, lower work table for minute operations; *l*, tables; *m*, stove; *n*, small water pipe; *o*, gutters for carrying off water; *p*, rain water cistern; *r*, pipes leading from the roof to the cistern; *s*, trap door for introducing coal into the coal cellar; *t*, door of communication; *u*, distilling apparatus; *v*, work table with shelves; *v'*, lower work table; *w*, table for using apparatus; *x*, fireplace with cooking vessels of different sizes; *y*, closed work table, for generating noxious gases; *z*, stove; *z''*, chimney; *tz*, two door communications; *aa*, book and instrument cases; *bb*, stove, whose pipe in winter heats the space for the water reservoir; *cc*, water reservoir; *dd*, steps to the coal cellar; *ff*, yard door; *f'f'*, window towards the laboratory; *g'g'*, window towards the old laboratory, P; *hh*, director's fireplace; *ii*, passage towards the pharmaceutical laboratory and the privy.

From the bare enumeration of these different parts of this vast laboratory, it is evident that the entire course of chemical instruction is very different from the method of lectures usual in academies. The reason of this is that satisfactory and extended chemical experiments require a large stock of apparatus and great conveniences for manipulation; as, also, a large amount of time. The oft-repeated and long-continued observations required in certain experiments, render it necessary for the laboratory to be arranged for the daily residence of the students. A proper instruction in chemistry generally commences with teaching those properties of elementary bodies which are calculated to furnish distinguishing characteristics. Instruction of this kind has, however, not merely for its object the elucidation of this knowledge in the form of a certain easily understood system; it is rather intended to exhibit those principal properties of matter by experiment, and first of all to teach by what means the single elements are to be obtained, or ascertained in any given compound, however complicated. This first part of practical chemistry is known as qualitative analysis, since its object is merely to ascertain the character of the elements composing a combination. After sufficient practice of the student in qualitative analysis, instruction in quantitative analysis follows next, or the investigation of the exact amount by weight of each element or body contained in a given substance, or in any of its combinations. It is especially necessary for the student to be exercised in the most varied

practical operations. A knack in handling delicate and expensive apparatus, and a constant habit of considering the most varied results which may ensue in combining single substances, must be acquired by the student in chemistry, besides the actual science which he studies.

MINERALOGY.

PLATES 32, 33, 34, 35, 36.

Introduction.

MINERALOGY is that part of natural science which treats of the unmixed, inorganic bodies occurring in nature, whether these be simple or compound. It may, under a certain point of view, be considered as a department or offshoot of chemistry, but is nevertheless as much entitled to a separate place among the sciences as geology or botany. It must indeed be treated of independently, since by determining the differences of individual minerals, and by ascertaining certain common characters, it brings the variety of inorganic nature into a position for proper appreciation; just as is done for the organic world by its two sisters, botany and geology. As occupied with inorganic matter, it stands in closest approximation to geology, this treating of the combination of mineral matter into rocks, and the distribution, stratification, degradation, or decomposition of these rocks, in various ways and in different parts of the globe. Mineralogy deals only with individual specimens from these various rocks, which it classifies according to certain systems, describes them according to their external and internal characters, and adds to this the assistance furnished by chemistry, in determining their atomic constitution.

The expression, "unmixed, simple, or compound inorganic bodies," requires some further explanation. The surface of the earth rarely affords the matter of its solids, its water, and its atmosphere, in an elementary, and consequently inseparable form. Indecomposable substances must be considered as simple matter furnished by nature. By far the greater number of mineral bodies are, however, not simple substances, but combinations of two or more such elements, in definite proportions, and in most cases even of a definite external form. Such compound bodies, to whose true character chemistry furnishes the only clue, are known as definite chemical combinations. On the surface of our earth, for ages exposed to the alternating influence of volcanic heat, of water, and of oxydation, we find these definite chemical combinations of elementary matter, united in the most varied manner and proportion, by mechanical agencies. These mixtures, then, which exhibit no definite proportion, by weight, of the different constituents, are excluded from the department of mineralogy. From this statement, we may more clearly see the intimate connexion between chemistry, mineralogy, and geology, as already hinted at. When we separate mineralogy from

chemistry, which in its system must, summarily at least, treat of all the combinations of matter, and consequently of all minerals, we must consider the analytical portion of the latter science as the instrument by which we construct the former on a sure basis. This indeed is the view which we have taken in the following pages.

1. Testing of Minerals, and the Apparatus Necessary.

The chemical analysis of a mineral is indispensable to a proper knowledge of it. This analysis once performed, however, it is not necessary to repeat it in every case; all that is needed being to determine, with certainty, one or more constituents. The *blowpipe* (*pl.* 32, *fig.* 1) serves this purpose. It consists of a tube through which air is blown from the mouth into an expansion of the instrument, where it is somewhat condensed; thence to emerge with some force, through a small aperture at the extremity of a fine lateral tube. On bringing this aperture of the blowpipe over the burning wick of a spirit or oil lamp, the fine current produced as just described, causes the flame to run out into an attenuated point (*fig.* 2) of extraordinary intensity of heat; this flame is the agent employed in conducting the investigations. Mineral bodies, to be tested by means of the blowpipe, are placed in very small quantity on a piece of charcoal or clay, or else held in a platinum spoon or forceps (*fig.* 3), and thus submitted to the flame. This consists of two cones, one within the other; the former being blue, the latter yellow. The greatest intensity of heat is found just beyond the end of the blue flame. The blue flame is called the flame of reduction, bodies being deoxydized in it; the yellow is the oxydizing flame, causing, in many cases, the combination of oxygen with the bodies in question. Thus we may learn the melting point of bodies, or their relation to heat; we may reduce an oxydized body to its base in the blue flame, and oxydize it, if at all possible, in the yellow. By the application of such acids as phosphoric or boracic, capable of resisting the decomposing action of the flame, we dissolve a small portion of the mineral in the flame, and thus ascertain the color of its various salts. Another construction of the blowpipe is given in *pl.* 32, *fig.* 4. Here it is screwed to a post with an attached stand, and can be set higher or lower along the post, for the sake of allowing a proper position with reference to the accompanying lamp. It thus permits the free use of both hands.

A physical examination must frequently be combined with the chemical in the determination of a mineral. Thus the knowledge of its specific gravity is of great importance. In addition to the ordinary methods which may be employed, Nicholson's areometer (*pl.* 32, *fig.* 5) is often used to great advantage. This consists essentially of the funnel *a*, the cylinder *b*, the rod *cm*, and the table or plate *d*. The instrument is so arranged that when set in distilled water, and a definite weight laid upon *d*, it will sink to a mark, *m*, made on the rod. To determine the specific gravity of a mineral it is laid on the plate *d*, when it will, of course, depress the

instrument in the water. Additional weights must be added to bring the mark *m* to the level of the water, and the amount of these weights subtracted from the standard weight already referred to, will be the weight of the mineral in the air. Call this weight *p*. Remove the mineral from the plate and place it in the funnel or hollow cone *a;* immersed in the water the areometer will not sink quite to *m*, but about to *c*, the body losing in water an amount of weight equal to that of a quantity of water of precisely the same volume with itself, or equal to that of the water displaced. Additional weights are now to be laid on *d* until the level *m* is again reached: this amount, which we will call *p'*, expresses the weight of an equal volume of water. We have thus ascertained the weight of precisely equal volumes of water and of our mineral; and as water is the standard taken, $\frac{p}{p'}$ will express the ratio of the two, or the specific gravity of the body. Thus $x : 1 :: p : p'$, and $x = \frac{p}{p'}$

The mineral must also be subjected to the tests afforded by electricity and magnetism. A simple instrument for ascertaining whether a mineral becomes electrical or not by friction, is represented in *pl.* 32, *fig.* 7^b. Its principal part consists of a horizontally suspended insulated metallic needle. Whenever a body becoming electric by friction is presented to the needle, this, if in its natural condition, will be attracted: on the contrary, no effect will be produced when the body is a conductor. *Fig.* 7^a is an instrument of similar purpose. At one end is placed a piece of tourmaline. On compressing the extremity of this between the fingers, the heat decomposes its neutral electricity, the positive passing over to the opposite extremity, and thus affecting the electrical state of the needles. The latter is insulated by a glass leg. On bringing any electric body near to the end of the needle, this will be attracted if the electricity be negative or resinous, and repelled if it be positive or vitreous. We are thus enabled to detect, not only the existence of free electricity in a body, but also its character. *Pl.* 32, *fig.* 6, presents a simple arrangement for determining the magnetism of a mineral. Here *a* is a magnetic needle, supported on the point of the pivot *b*, and, when permitted to play freely, taking up a position in the magnetic meridian. On bringing a magnetic mineral near to the poles of the needle, this will either be attracted or repelled, as the end of the needle to which the mineral is presented is of unlike or like character with the corresponding part of the latter. Should there be no free magnetism in the mineral, there will of course be no deflection of the needle.

The sensible internal peculiarities of minerals are very numerous. Thus a fresh fracture may be produced, and the color and degree of translucency or transparency of small chips observed; the color also of the powder may be compared with that of the solid mass. The shape of the natural fragments is also to be noted. Thus galena breaks into cubes, calcareous spar into rhombohedrons, and sulphuret of antimony into pointed crystals. In the natural cleavage of different minerals we observe a greater or less

amount of roughness, of unctuosity or softness, and of polish. Some give out a peculiar sound when struck, or afford a peculiar taste, or smell, of which others again may be destitute. The determination of their hardness is of great value in distinguishing minerals, for which purpose we may employ the ingenious method of Mohs, of rubbing fragments of two different species together, and examining which of the two scratches the other. The different degrees of hardness may thus be represented by a scale beginning with the softest; and any mineral in the scale will be scratched by those below, but not above it. The hardness of any mineral may then be subjected to comparison with that of the standard. This scale of hardness, as introduced by Mohs, is as follows:

1. Talc; common laminated green variety.
2. Uncrystallized gypsum.
2½. Foliated mica.
3. Transparent calcareous spar.
4. Crystallized fluor spar.
5. Apatite.
5½. Scapolite-crystalline.
6. Feldspar-white, cleavable variety.
7. Transparent quartz.
8. Transparent topaz.
9. Corundum (sapphire).
10. Diamond.

Thus, a mineral which abrades feldspar, but not topaz, is said to have a hardness of seven, equivalent to that of transparent quartz, &c. The external shape of minerals is also of great interest and importance. This, indeed, in many cases is objective, being determined by that of other bodies; sometimes by the gravity of the mass itself; but in most instances there is another subjective form, independent of extraneous influences, and peculiar to the particular species of mineral. Direct observation first of all teaches us that the natural form of every mineral is a solid, bounded by plane surfaces. A still closer examination enables us to ascertain that the true external shape of a mineral is that of a closed figure, bounded by sharp edges and angles, the points and lines of intersection of the planes just mentioned. Bodies thus inclosed are called crystals. In view of the apparently infinite variety of crystalline forms, we might at first be induced to suppose that the precise outline of any body is capable of being infinitely and indefinitely varied; observation, however, shows this not to be the case, nature here exhibiting a remarkable simplicity, and a most admirable law. As mineralogy deals with solid bodies, that method for their determination were most desirable which mathematics shows to be the simplest. A body has height, thickness, and breadth; thus, three dimensions. Clearly to illustrate and compare these three forms of extension, let us suppose the height to be indicated by a vertical line, which shall in future be called the principal axis. Let other lines be passed through this principal axis, at

right angles to it and to each other, these lines to be called the secondary axes. These three axes measure the three dimensions of a body, and it will be found on examining these dimensions that the natural distances between the surfaces bounding the crystals are not without a rule, but are rather determined by laws referable to variations in the ratio of the length and angular relations of these axes. According to various definite ratios between the three axes, we may group a large number of, at first, apparently different crystalline forms. However different the ratio of three such lines may be in respect to their length, estimated from their middle, or point of intersection, or however varied the angle of inclination, nevertheless we know of but six essentially different sets of axial proportions. The simplest figures determined directly by these axes are called primary forms. All the primary forms, with the secondary forms derived from them, however different they may seem, are referable to one of six systems of crystallization.

2. *Crystallography.*

That part of mineralogy relating to systems of crystallization, is called Crystallography. The systems referred to in the preceding paragraph are briefly as follows :

I. The Monometric System, *Dana.* The Regular System (Das regulaire System), *Weiss.* Tessular, *Mohs.* Tesseral, *Naumann.* Isometric, *Hausmann.*

The character of this system is such that, if a certain point be taken, and three axes be drawn through this point, at right angles to each other, they will all be bounded at equal distances by a solid angle, a face, or an edge. It is therefore a matter of indifference which axis we make the vertical or primary, all three being of equal value. The regular octahedron is generally taken as the type of this system, the others being derived from it. The most general forms are as follows :

1. The *regular octahedron* (*pl.* 32, *figs.* 11 and 12). This is a solid inclosed by eight equilateral triangular faces, intersecting each other, in six solid angles, and twelve edges. Connecting each opposite pair of solid angles will give us the three axes, intersecting each other at right angles in a common point, and of the same length from the point of intersection. Whatever two opposite angles be selected as the limits of the vertical axis, the others will always have the same relative situation. Natural crystals, however, do not always exhibit the perfect symmetry thus indicated. Distortions frequently occur, one of which is given hereafter as a derivative of the octahedron. Thus if we intersect any two parallel faces of this solid, by a plane parallel to another face, or if we move one face parallel to itself, nearer to the centre, a hexagon (*fig.* 11, *a*, *a'*, *a''*, *a'''*), will be obtained by the lines of intersection.

By moving two parallel faces towards the centre, these with the six other abbreviated faces will inclose an octahedron abbreviated to a six-sided plate (*fig.* 13). Octahedrons distorted in this manner are more abundantly

found than absolutely symmetrical octahedrons: it must nevertheless be observed, that such distortions are always produced by some external impediment, and that nature, in the entire absence of all obstructing influences, always exhibits perfect symmetry. This is true, not for octahedrons alone, but for all crystals.

2. *The cube* (*fig.* 14) is produced from the octahedron, by truncating its solid angles by planes perpendicular to the axes. Here the axes are again all equal, and connect the centres of opposite faces. *Fig.* 15 shows the relation of the cube to the octahedron.

3. *The cubic octahedron* (*figs.* 16 and 17) is obtained from the cube, by truncating the six corners, until the old faces again become squares. *a* and *b* are new faces parallel to the old faces of the obliterated octahedron.

4. *The rhombic dodecahedron* (*pl.* 32, *fig.* 18) is produced from the cube by the truncation of its edges, until the original faces are obliterated. This solid has twelve rhombic faces, twenty-four equal edges, and fourteen solid angles. Of these solid angles, six are formed, each by four rhombs meeting by their acute angles; and eight, each by three rhombs meeting by their obtuse angles. The relation of the rhombic dodecahedron to the cube is shown in *fig.* 19.

5. *The pyramidal cube,* or *tetrahexahedron* (*fig.* 20), is produced by placing a four-sided pyramid on each face of the cube.

The cubic octahedron has already shown that a crystal may be inclosed by faces belonging to two different forms of crystals. This case is often repeated. Thus, in *figs.* 21 and 24, the cube is represented with dodecahedral faces replacing its edges. *Fig.* 22 shows an octahedron, with dodecahedral faces, *a*, and cube faces, *b*; *c*, indicating what is left of the octahedron. *Fig.* 23 represents an octahedron passing into a dodecahedron: *fig.* 25 is a combination of cube faces and those of the pyramidal cube; or a cube with its edges bevelled. *Fig.* 30 is the trapezohedron, or tetragonal trisoctahedron; a solid bounded by twenty-four equal trapezia. It can be derived from the octahedron by replacing its corners by four faces, or by replacing each corner of the cube by three faces (*fig.* 28).

The figures hitherto derived from the primary forms have been produced by modifying all the similar parts of the primary simultaneously. Such forms are called holohedral. Hemihedral forms of crystals occur in equal number. These are forms in which half of the similar parts of the crystals are modified alike, independently of the other half. Some of these forms are:

6. *The tetrahedron* (*fig.* 26), a solid, inclosed by four equilateral triangles. *Fig.* 27 represents an octahedron passing into a tetrahedron, in which the faces, *a*, indicate what is left of the octahedron faces. A form of frequent occurrence, and likewise belonging to this place is:

7. *The pentagonal dodecahedron,* or *hemi-tetrahexahedron* (*fig.* 29). This is a hemihedral form derived from the pyramidal cube, and bounded by twelve equal pentagons.

We may remark, in reference to this as well as other systems, that all the different forms belonging to one and the same system, may occur in the

same mineral. Thus iron pyrites or sulphuret of iron occurs in cubes, octahedrons, pentagonal dodecahedrons, rhombic dodecahedrons: frequently in the same crystal we may have faces of all these different forms.

II. The Dimetric System, *Dana*. Das viergliederige System, *Weiss*. Pyramidal, *Mohs*. Tetragonal, *Naumann*. Monodimetric, *Hausmann*.

The fundamental form of this system is an octahedron with a longer or shorter vertical axis and two equal lateral axes (the three axes all at right angles to each other).

1. *The Square Octahedron*. It is called obtuse (*fig*. 32) when the vertical axis is shorter than the other, and acute (*fig*. 33) when longer.

The figures of the derivative forms are based on these proportions of the primary axes. As the vertical axis is always unequal in respect to two equal lateral axes, there will be different values in the derivatives. Thus the two corners through which the primary axis passes (*pl*. 32, *fig*. 34) may be truncated without the four corners of the secondary axes requiring a similar truncation. Elongations and contractions may occur in the direction of the primary axis, while the two secondaries mutually retain an equality of length.

The acute, like the obtuse octahedron, has the same number of faces, edges, and corners, or solid angles, as the regular; the base is in all a square; the side triangles, however, bounding the solid, are in the former isosceles, in the latter equilateral. The derivative forms from the square octahedron are, the octahedron (*fig*. 39) with truncated lateral edges: *fig*. 38 with truncated, and *fig*. 46 with bevelled basal edges. Also the octahedron with the corners of the vertical axis replaced by four plane faces (*fig*. 49).

2. *The Right Square Prism* (*fig*. 35). It is produced by truncating the four basal edges of the octahedron, as also the extremities of the vertical axis. The figure is bounded by four equal lateral rectangles and two terminal squares. *Fig*. 37 represents the right square prism, with its corners truncated until the terminal faces are replaced, each by a solid angle.

3. *The Regular Eight-sided Prism* (*fig*. 36) is obtained by bevelling the vertical edges of the right square prism. The double eight-sided pyramid (*fig*. 40) is produced by cutting off the basal edges of the eight-sided right prism (*fig*. 36), by planes meeting at the extremities of the vertical axis, and obliterating the lateral faces.

4. *The Twelve-sided Prism* (*fig*. 41) is produced by bevelling the vertical edges of the right square prism, without obliterating the lateral faces, as in the regular eight-sided prism.

5. *The Square Plate, with Four Bevelled Edges* (*fig*. 82), is produced by truncating the extremities of the square octahedron.

III. The Trimetric System, *Dana*. Das zwei-und-zweigliederige System, *Weiss*. Orthotype, *Mohs*. Rhombic, *Naumann*. Holohedral-rhomoic, *Breithaupt*.

The axes in this system are at right angles to each other, but all of unequal length. The fundamental form is:

1. *The Rhombic Octahedron.* If we suppose the square base of the preceding system to become oblique, a rhomb will be produced. If we suppose the lateral axes to occupy the place of diagonals to this rhomb, one will connect the acute and the other the obtuse angles, and while at right angles to each other, will be of unequal lengths. The vertical axis, passing through the point of intersection, and perpendicular to their plane, is either shorter than the lateral, in which case we have the obtuse rhombic octahedron (*pl.* 32, *fig.* 47^a), or else more elongated, producing the acute rhombic octahedron (*pl.* 32, *fig.* 47^e).

Since all three axes are unequal, it is a matter of indifference which we take as the principal or vertical axis. Having assumed one, those two corners alone have equal crystallographical value which lie on one and the same axis. Any two such corners may, for instance, be bevelled (*fig.* 48), without this modification needing to be extended to the other corners. The general shape of this form is that of the square octahedron, only the base here is rhomboidal. Thus the twelve edges of this octahedron are different in the whole of three different kinds. Derivative forms from this are:

2. *The rectangular prism* (*fig.* 56). It is produced by passing planes through the rhombic octahedron at right angles to the axes. Supposing these to increase until they intersect and truncate the two extremities of the primary axis, we shall obtain this figure. Sharpening the lateral faces of this prism, we shall obtain an octahedron (*fig.* 47^b), whose base is a rectangle. *Figs.* 44, 45, 57, and 58, represent modifications of this octahedron.

3. *The right rhombic prism,* terminated by the faces of the rhombic octahedron (*fig.* 69). Truncating the four horizontal basal edges of the rhombic octahedron by planes parallel to the vertical axis, and letting them enlarge until they intersect, we shall have this figure. It may be considered as the passage of the rhombic octahedron to the following.

4. *The right rhombic prism* (*fig.* 50). This is produced by truncating the two solid angles of the vertical axis, and letting the new faces thus formed enlarge until they intersect the faces truncating the basal edges of the last figure, these also being supposed to be extended. The figure thus formed will be bounded by two rhombs and four rectangles.

5. *The irregular six-sided prism* (*fig.* 51) is formed from the preceding by truncating the two obtuse or the two acute lateral edges.

6. *The irregular eight-sided prism* (*fig.* 52) is produced when the acute and obtuse lateral edges are so replaced by faces as still to leave the original lateral faces.

7. *Figs.* 53, 54, and 55, present some combinations of prisms and octahedrons, belonging to this same system, and frequently observed in certain well known salts. *Figs.* 53 and 54 are crystals of saltpetre. *Fig.* 55 often occurs in sulphate of tin.

IV. The Monoclinic System, *Dana.* Das zwei-und-eingliederige System, *Weiss.* Heminorthotype, *Mohs.* Monoclinohedric, *Naumann.*

The axes by which we measure the dimensions of this system are two lateral, unequal, crossing each other at a right angle, and a third oblique to one of the lateral, but at right angles with the other. Considering an octahedron as belonging to this system, its upper and lower faces would be different. It is customary to consider an oblique rhombic prism as the primary form, whose extremities stand perpendicularly to the lateral edges, and at an oblique angle with reference to the other two. From this prism the other forms may be derived as before. *Pl.* 32, *figs.* 59 and 60, represent two prisms in which two edges are truncated by the face *a*, producing oblique six-sided prisms. *Fig.* 61 represents an octahedron with half the edges truncated. *Fig.* 62 is a prism corresponding to the case in which half the basal edges are truncated.

V. The Triclinic System, *Dana.* Das Ein-und-eingliederige System, *Weiss.* Anorthotype, *Mohs.* Triclinohedral, *Naumann.*

An oblique rhomboidal prism is the basis of this system. All three axes are here oblique and unequal. A prism of this character is shown in *figs.* 64 and 65. In this system only two parallel faces and two opposite edges are of like value. For this reason we see the truncation of the edges extended only to two diagonally opposite edges, as in *fig.* 63. The inclination of the plane which truncates these edges is different with respect to one face of the edge from the other; and the six-sided prism (*fig.* 66) is consequently irregular.

VI. The Hexagonal System. Das Sechsgliederige System, *Weiss.* Rhombohedral, *Mohs.* Hexagonal, *Naumann, Dana.* Monotrimetric, *Hausmann.*

This system exhibits a striking peculiarity, as compared with the others. While, in the preceding systems, the dimensions of bodies were given in the least number of axes (namely, three) in which their exteriors could be considered; the simplest conditions are obtained by assuming four axes. Three of them lie in one plane, and having equal inclination to each other, are of equal length: they thus form the diagonals of a regular hexagon. The fourth, assumed as the vertical axis, is unequal to the three others, and stands perpendicular to their plane. As the primary form of this system we may assume the double six-sided pyramid (*figs.* 67 and 73). This is a solid bounded by twelve isosceles triangles. Truncating the basal edges by planes parallel to the vertical axes, will give us the pyramidal six-sided prism (*fig.* 68). Truncating the terminal solid angles of *fig.* 68 will give us the regular six-sided prism, with right terminal faces (*figs.* 70 and 71). *Fig.* 72 is obtained by truncating the corners of *fig.* 70; bevelling the six vertical edges we have the twelve-sided prism (*fig.* 42); and by bevelling four edges the prism (*fig.* 76). A form of this system, occurring frequently in calcareous spar, is the scalene octahedron (*fig.* 74). The hemihedral shape of the double six-sided pyramid, or the rhombohedron (*pl.* 32, *fig.* 75), is often assumed as the primary form of this system. One and the same crystal is thus frequently inclosed by faces of several

different rhombohedrons, derived from the fundamental rhombohedrons. *Figs.* 77 and 78 represent the natural situation of two rhombohedrons.

3. Internal Structure of Crystals.

What we have said in the preceding section has reference to the external form only, whatever might have been the relation in this respect between the different figures. A close investigation, however, discloses the fact, that they sustain remarkable relations in respect to their internal structure. Many crystals, on being broken, naturally separate into definite forms, as calcareous spar into rhombohedrons, and galena into cubes. Nearly all crystals may be split, by means of a sharp knife and a hammer, into certain other forms of the same system. Thus fluor spar may, by cleavage, be converted from a cube into a regular octahedron. We may, in many cases, therefore, suppose a crystal to be a mass built up of those elementary forms into which they split. Hauy, the founder of the science of crystallography, assumed an elementary form for each system, and supposed all forms belonging to a system as composed of aggregations of such simple forms. It would rather seem, however, that each crystal is composed of very small crystals of the same form; that a cube must be composed of smaller cubes; and that an octahedron is not composed of regularly decreasing layers of small cubes, as according to *figs.* 92 and 93, given by Hauy, but consists of a mass of very small octahedrons. Besides these peculiarities, there are crystalline formations of interest, which appear to consist of a series of layers, regularly applied to an originally minute crystal. On making a section of such a crystal, we may see a series of concentric outlines inclosing the central nucleus, these different outlines indicating so many different layers, being often of different colors. This feature is often seen in six-sided prisms of calcareous spar, and in quartz (*figs.* 88 and 89). Besides the fact that a large crystal may be produced by a regular aggregation of smaller ones, several distinct crystals may unite or grow together, and produce a definite form. Combinations consisting of two individuals are called twin-crystals. Groups of a similar character, consisting of many individuals, are frequently found. Substances which crystallize in right rhombic prisms, sometimes exhibit a stellated grouping (*fig.* 79).

4. Measurement of the Angles of Crystals, and the Necessary Apparatus.

In section two it has been shown that the positions of the surfaces inclosing a crystal depend on the axes. Hence it follows, that as these axes occupy a definite angular relation to each other, the faces of the crystal must mutually exhibit the same relation. In consequence of this dependence we are enabled to tell the inclination of the axes, knowing that

of the faces, and consequently to determine the system. Certain instruments are, however, necessary, accurately to determine the precise angle made by two plane faces with each other.

The oldest and simplest instrument is the *common goniometer* (*pl.* 32, *fig.* 8). It is of easy use, and very convenient, when we do not require an angle with any very great accuracy. To determine an interfacial angle, one face must be applied to *an*, with the edge of inclination opposite to the centre of the diameter. The arm, *e'd*, is then to be brought around until its edge rests on the other face: the crystal is thus accurately inclosed between two radii of the semicircular scale. The angle indicated on the point of the scale, crossed by the prolonged movable radius or arm, indicates the angle of inclination desired, provided that the edge, *ab*, coincide accurately with the single diameter of the semicircle. This diameter is jointed at *b*, to admit of measuring angles which are partially imbedded. When the application of the two radii is completed, the joint, *m*, is to be tightened, and the whole brought back, until *ab* again coincides with the diameter. The inclination of the planes not intersecting each other in an edge, may also be measured by turning the movable arm until the two edges of the instrument are parallel to, or coincide with the plane faces in question.

Much more accurate measurements may be obtained by the use of *Wollaston's reflecting goniometer* (*pl.* 32, *fig.* 10), an instrument recently very much improved. Here, *ab* is a disk turning on an axis, *el*, carrying a circle graduated to degrees on its periphery. Rotation takes place in such a manner that the disks, *fg*, *hi*, and *ab*, all turn at the same time with the horizontal cylindrical body forming their axis; in this axis another axis, *el*, may itself be turned by means of the button, *cd*; *k* is a clamp-screw, by means of which the entire system, *fg*, *hi*, *ab*, may be fixed by tightening *hi*; at the same time that this is done, the inner axis, *el*, may still be turned independently of the button *cd*, and any required position thus be given to the arm *lp*. This arm carries the jointed continuation, *pm*, turning on *p*. At *n* the crystal to be measured is fixed, and so adjusted, that the edge in which the two planes (whose inclination is to be ascertained) intersect shall be parallel to the axis *el*. The circle, *ab*, is now fixed by means of the screw *k*, and the axis *el*, turned by means of the button *cd*, so that the image of some distant object, as the horizontal bar of an opposite window, may be seen in one of the planes of the crystal. The spot from which the image is seen in the face of the crystal is marked by drawing a black line on paper, and so placing this paper as that its line may be seen as a continuation of the reflected line of the window-bar in the crystal. If we were to suppose a thin metal plate, polished on both sides, to be fixed at *n*, instead of the crystal, after obtaining the image of the window-bar in one of the faces, as just described, we should have to rotate it just 180° to see the same image in the other face. The case is similar in respect to our two crystal faces. If two of these be parallel, like the faces of our plate, the angle thus obtained will be 180°. Any other inclination will be obtained in a similar manner. The operation must be commenced by

bringing 180° on the disk directly opposite to the 0° of the vernier *a*, and establishing a perfect parallelism between the edge of our crystal and the standard window-bar. The image of the window-bar, seen at this time, must be on a line with the black line drawn on the paper already referred to. The whole apparatus, clamped together, is next to be turned until the same bar is seen in the other face, and on a line with the line on the paper. The angle through which the apparatus has been rotated, as read off on the vernier, will be the angle of inclination of the two faces. For further remarks on the subject of the reflecting goniometer see Optics.

For very large crystals, in which the preceding form of reflecting goniometer cannot be used, we may advantageously employ the goniometer of Gambay (*pl.* 32, *fig.* 9). It consists principally of a horizontal and rotating disk, AB, supported by a stand, C. The crystal being fixed in the centre of the smaller disk, *ab*, the telescope, D, is now directed towards the crystal, and this turned until some distant object, as a distant tower, shall be seen in the cross-hair of the former. The angle through which the disk, *ab*, bearing the crystal, must be turned to see this same image crossed by the cross-hair in the other face of the crystal, will be the angle of inclination of the two faces.

5. Special Mineralogy.

The succeeding descriptions of the minerals figured in plates 33, 34, 35, and 36, will allow of a brief survey of the application of crystallography; as also of the manner of mineralogical examinations. The number of single minerals already determined, with great exactness, is so great, that we can no more omit system in mineralogy, than we can in botany or zoology. The minerals figured in our plates have therefore been, to a certain extent, arranged according to the system of Hausmann, which is the one we have deemed best for our purpose.

We thus divide minerals into ten classes: 1, Metalloids; 2, Native Metals; 3, Tellurids; 4, Antimonids; 5, Arsenids; 6, Selenids; 7, Sulphurids; 8, Oxydes; 9, Silicates; 10, Salts.

Class 1. *Metalloids.*—Hausmann.

Simple non-metallic bodies, which disappear when heated in the air or in oxygen, forming a combination with the latter.

1. *Sulphur.*

This is a substance occurring in great abundance. It is found both simple or native, and combined with other bodies. The combinations most generally met with are those with the metals, and with oxygen; less abundantly with hydrogen. It is frequently, although in small quantities, found as an essential ingredient in organic substances. Native sulphur is of a yellow color, and has a specific gravity of 2.07. It is a non-conductor of heat, and becomes negatively electric by friction. It is one of those

substances whose crystals cannot all be referred to the same system; it is therefore dimorphous. The crystals of native sulphur are rhombic octahedrons (*pl.* 33, *figs.* 4, 26, 27, 28, and 29), whose sharp solid angles are frequently truncated, as in *fig.* 27. Those crystals, however, which shoot out in melted sulphur when cooling, belong to the monoclinic system; they appear generally in the shape of long, thin, and brittle needle-shaped crystals, as shown in *fig.* 3. Sulphur has a resinous lustre, is sub-translucent, and gives out a peculiar odor when rubbed. It readily melts by the application of heat, and then takes fire when exposed to the air, burning with the production of sulphurous acid gas, and a suffocating odor. Native sulphur is of frequent occurrence in different formations, but rarely in large quantities. The finest crystals are found in the valleys of Noto and Mazzaro, in Sicily. It is found in very large quantities about recent or extinct volcanoes, as in the Solfataro near Naples. Sulphur often occurs in an impure earthy condition in large masses, and is deposited from sulphur springs. Most of the sulphur of commerce is obtained from Sicily, or else is derived from the sulphurets. In combination with metals it is universally distributed, and in large quantities, and is obtained in the reduction of the metal as a secondary product. Its applications are very numerous, especially in the different forms of matches, gunpowder, &c.

2. *Carbon.*

Carbon occurs in a naturally pure and crystallized state, under forms belonging to two different systems, namely, as diamond and as graphite. It likewise occurs in an amorphous condition as stone coal, impure by being mixed with the other ingredients forming the carbonized plant. The purest form of carbon, the diamond, exhibits a crystallization belonging to the regular system. The most common forms of the diamond are the regular octahedron (*fig.* 42), and the regular octahedron with the faces of the rhombic dodecahedron (*fig.* 43). It more rarely occurs in cubes, tetrahedrons (*fig.* 51), and trigonal-polyhedrons.

The diamond was first found in the East Indies. The most important diamond mines at present, are, in India, between Golconda and Masulipatam, in Brazil, and in Borneo and Malacca. Here they occur in alluvial soils, lying loose in the sands of plains, and in the beds of rivers, or in the ferruginous clay and recent conglomerate composed of quartz grains cemented by ferruginous sand. Nothing certain is known of the origin of the diamond. Of all gems this is the most esteemed, adding to its other properties that of being the hardest known. Its refractive power is extraordinary, and Newton, as early as 1675, concluded from this quality, peculiarly high in bodies containing carbon, that the diamond must be combustible. Its combustion was first effected by the Florentine Academy in 1694, and Lavoisier, by proving it to consist of pure carbon, first announced its true nature. It is a non-conductor of electricity, and has a specific gravity of 3.5. It occurs quite colorless, or else grey, brown, black, yellow, green, and blue. It is used very advantageously as a means of cutting glass; but its chief application is as an ornamental gem, after being ground in certain regular shapes, whose end is the production of the peculiar and sparkling

lustre so much admired. Colorless diamonds are most esteemed as ornaments. The impure and small diamonds are reduced to powder to be used in grinding the rest. The grinding of the diamond requires great skill, and the different forms imparted have definite names. The principal of these are: 1, The brilliant (*pl.* 32, *figs.* 85, 87, 90); 2, The rosette or rose (*figs.* 84, 91). Older forms, now rarely imitated, are shown in *figs.* 80, 81, 82, 83, and 86.

The second form of carbon is graphite, known also as plumbago and blacklead. It also occurs so pure as to leave but little ash when burned. Certain characteristics distinguish it very decidedly from the diamond: it does not crystallize in the regular system, but in six-sided plates; is a good conductor of electricity; and has a low specific gravity, 2.14—2.27. Graphite is soft, unctuous to the touch, of a steel-grey metallic lustre, and opake. In thin plates it is flexible. It occurs in beds and layers in primitive rocks, gneiss, granite, primitive limestone, greywacke, and greenstone. The principal localities are in England, Germany, Norway, Greenland, France, Spain, the United States, &c. Its uses are various, being employed in fabricating pencils, in the construction of crucibles and small furnaces, as an anti-attritient, &c. The best graphite for the manufacture of lead pencils comes from the Borrowdale mine, England. The poorer graphite is extensively used, and, by pressure, good pencils are made.

The third kind of carbon, the uncrystallized, which occurs in various combinations with hydrogen and oxygen, will be discussed under the head of Geology.

Class 2. *Native Metals.*

Simple bodies, or occurring as mixtures or alloys with one another, in variable or indefinite proportion; specific gravity from 7 to 22. All possess a metallic lustre, or at least acquire it under the burnisher. They are opake, and good conductors of electricity.

1. *Native Iron.*

Iron rarely occurs in the native or uncombined condition. It is found as such in small masses or grains only in mica slate, and in large masses as meteoric iron. In its combinations with the other elements, and especially oxygen and sulphur, it is the most generally and abundantly diffused of all metals. Metallic iron was known in very ancient times, since Moses speaks of iron knives. With respect, however, to the manner in which the ancients obtained their iron, we know little or nothing, except as far as it may have been derived from aerolites. Instead of iron the ancient Greeks used a mixture of tin and copper. Meteoric iron sometimes occurs in large masses. One of these, found in South America, weighed nearly 40,000 lbs. Remarkable specimens, also, are found in the cabinets of St. Petersburg and Vienna. One in the cabinet of Yale College, at Newhaven, weighs 1635 lbs. However rare the fall of meteors may be, they are mentioned by as early an author as Pliny. The fact of their existence was subsequently doubted,

until Chladni, in 1794, took up the question, and soon accumulated such a mass of proof as to satisfy the most sceptical. Meteoric iron generally occurs in jagged and roughly-vesiculated fragments (*pl.* 33, *fig.* 1). It is not perfectly pure, generally containing a slight quantity of some other metals, of which nickel has been found in all undoubted meteorites. In the meteoric iron of Ellbogen were found, in one hundred parts: iron, 88.231; nickel, 8.715; cobalt, 0.762; and manganese, 0.249. Meteoric iron has a crystalline texture by which it is recognisable. By sawing off a corner and polishing it, the application of dilute nitric acid will develope triangular and lozenge-shaped figures, mostly of 60—120° inclination, the sides all bounded by double lines. These figures, shown in *fig.* 7, are known as the Weidmannstedtian figures, from their discoverer. The iron of commerce is obtained in furnaces by reduction from oxydes or carbonates.

2. *Native Silver.*

Silver frequently occurs native in silver mines, and also alloyed with other metals or simple bodies; in the form of sulphuret of silver it is very abundant. Native silver occurs crystallized (*pl.* 33, *fig.* 9), exhibiting the forms of the regular system, as the cube, the rhombic dodecahedron (*fig.* 30), the pyramidal cube (*fig.* 40), and the octahedron (*fig.* 42); or else it is found in filiform (*fig.* 16), or in arborescent (*fig.* 12) shapes, sometimes in coarse masses, in plates, &c. Native silver, like most native metals, is not perfectly pure, containing a variable amount of gold, copper, antimony, and arsenic, without any change being produced in its external or crystalline form. Its color alone is affected in these mixtures, varying from silver-white to brassy-yellow. Silver is very ductile and malleable, and difficult of fusion. It occurs mostly in veins, more seldom in beds in primitive rocks, granite, porphyry, and gneiss; in transition and stratified rocks, accompanied by barytes, hornstone, or calcareous spar. The principal localities of native silver are in Saxony, Bohemia, Hungary, the Hartz, Norway, Siberia, Mexico, &c. It occurs associated with the native copper of Lake Superior. The silver of commerce is obtained partly from native silver, partly from the sulphuret, or from combinations of the sulphuret with other sulphurets, such as antimony and arsenic. It is found in especial quantity in reducing lead from galena (sulphuret of lead). It is obtained by reduction, by amalgamation, or by cupellation.

3. *Native Gold.*

Gold rarely occurs in any other form than native. In this state, like silver, it is alloyed at times with other metals, in variable, not definite proportions. The principal alloys are with silver, copper, iron, platinum, iridium, and palladium, the crystalline form not being necessarily changed thereby. The color of these alloys varies from golden-yellow to silvery-white. It has a specific gravity of from twelve to twenty, is rather soft, and exceedingly extensible. The crystals of native gold belong to the regular system; the most common forms are shown in *pl.* 33, *figs.* 32, 33, 35, 36, 40, 41, 42, 43, 44, 45. It also occurs in various uncrystallized forms; in arborescent ramifications, as in *fig.* 14; also in filiform and reticulated masses, in coarse lumps, scales, and grains. Its original locality is in veins

and laminæ in quartz, in talcose micaceous rocks, greenstone, and often associated with sulphuret of iron. It is often, however, found in loose soils, in sands, and in river beds. Most of the gold recently obtained in California is from localities of the kind last mentioned. Pure gold is the most malleable of all metals, leaves having been beaten so thin, that 282,000 are required to be superimposed to make an inch. It melts at 2192° F., and is vaporized in the focus of a large burning-glass, or in the flame of the oxy-hydrogen blowpipe.

4. *Native Mercury.*

Mercury sometimes occurs native, although it is generally obtained from certain ores. It is the only metal which is liquid at ordinary temperatures, becoming solidified only at and under — 39° F. The crystals which form in this state belong to the monometric system, and are principally octahedrons (*fig.* 33). It occurs as an amalgam, mixed with silver, in different proportions. The amalgam is generally stiff, rather brittle, and whitens copper when rubbed with it. Mercury mixed with silver presents the crystalline forms of both metals, which, at any rate, belong to the same system. The principal forms of such crystallization are shown in *pl.* 33, *figs.* 30, 45, 61, 62, 63. Mercury is obtained principally from the mines of Idria in Austria, and Almaden in Spain. Valuable deposits of cinnabar, or sulphuret of mercury, have recently been discovered in California.

5. *Native Copper.*

Although most of the copper of commerce is obtained from its ores, yet it occasionally occurs in enormous masses, as a native metal. It is sometimes found crystallized, the crystals belonging to the regular system. The principal forms are represented in *figs.* 24, 30, 36, 40, 41. Most generally, however, the crystalline structure is not so evident, the metal occurring in various amorphous shapes; in veins (*fig.* 13) and beds in granite, syenite, grauwacke, slate, red sandstone, &c. Its principal localities are Hungary, Siberia, Brazil, China, Japan, and North America. The region about Lake Superior furnishes the largest masses of any known; one now in Washington, weighing 3704lbs., and others occurring of such enormous size as to present almost insuperable difficulties in the way of following out more manageable deposits. A mass was quarried out in the Cliff Mines (Lake Superior region), the weight of which was estimated at eighty tons.

6. *Native Bismuth.*

This metal rarely occurs pure in nature, being generally combined with arsenic. It occurs in crystals of a rhombohedral form, nearly cubes in appearance. Metallic bismuth is of a whitish steel color, with a slight tinge of rose-red, and on being broken exhibits a coarsely foliated crystalline texture. This is shown in great perfection by melting the metal in a crucible, and after allowing a hard crust to form, piercing this, and permitting the still liquid portion to run out. *Pl.* 33, *figs.* 5 and 10, represent the crystallizations thus obtained. Native bismuth is found in veins, in gneiss, granite, rarely in clay-slate; generally accompanied by

other metals. The richest localities are in Northern Europe. The only one known in the United States is in Connecticut. Bismuth is used principally in the formation of such alloys as require to become liquified at rather low temperatures.

7. *Native Antimony.*

This rarely occurs native; when found it is of a tin-white color, rather brittle, and when crystallized, forms obtuse rhombohedrons (*figs.* 25, 31, 38). Specific gravity 6.5—6.8. It is not ductile, but flies to pieces under the hammer; is readily fused, and burns before the blowpipe with the evolution of a dense smoke of oxyde, deposited in crystals in the vicinity of the burning mass. It occurs in veins and lamellar concretions in crystalline rocks, associated with arsenic, silver, galena, &c., in the Hartz, Bohemia, Sweden, and in Dauphiny. The uses of antimony are various: it is employed in the arts in the composition of various alloys; thus antimony and lead constitute type-metal. Its pharmaceutical applications are numerous; thus the sulphuret is a very powerful medicine, known as kermes, and the oxyde of antimony is much used in various combinations.

8. *Native Arsenic.*

This metal is frequently found native. It occurs in acute rhombohedrons when crystallized (*pl.* 33, *fig.* 25), or in amorphous masses, or in small concave scales set one within the other. It tarnishes readily in the air, becoming nearly black, and losing its original tin-white color and metallic lustre. In its native state it is frequently called cobalt by the miners, on account of its deceiving them in their expectation of finding a lump of metal after roasting the ore containing it; the process actually converting the metal into arsenious acid, which passes off in vapor. The presence of this vapor may readily be known by its strong smell like garlic. This vapor is highly poisonous. The substance known in commerce as arsenic is not the metal, but an acid combination with oxygen forming arsenious acid. It is produced by roasting the arseniurets of cobalt, iron, or nickel, and collecting the vapors in long chimneys or iron receivers. It occurs first as a hard, clear glass, which subsequently becomes an enamel white. Although exceedingly poisonous, it is an indispensable agent in the arts, especially in those of coloring and glass-making. It is an invaluable agent in the preservation of objects of natural history, being applied, mixed with water, alcohol, or whiskey, to those surfaces which it is desired to preserve from putrefaction, or the attacks of various insects. It is also used in poisoning vermin: fly-powder is a preparation of arsenious acid. Sulphurets of arsenic occur both native and manufactured: one of them is the golden-yellow orpiment; the other, realgar, of a fiery red. The oxygen combinations of arsenic are all acids, and, with the sulphurets, are of great importance as medicinal agents

Class 3. *Tellurids.*—Hausmann.

The minerals of this class are combinations of electro-positive metals

with tellurium. These tellurids are known by their partial volatilization when heated in a glass tube, giving off vapor of tellurous acid, which is deposited on the sides of the tube. On applying additional heat to this deposit, it first melts and then evaporates.

These combinations are very rare, and not very widely diffused. Those best known are graphic tellurium, white tellurium, laminated tellurium, and auro-tellurite, being mostly combinations with gold, silver, lead, copper, sulphur, &c. Those which principally occur in Transylvania are valuable mainly for the gold they contain.

Class 4. *Antimonids.*—Hausmann.

These also are known by their behavior when heated in a glass tube. The vapor, however, which is deposited in a crust on the sides of the tube, volatilizes on being heated without first melting like the tellurids.

1. *Antimonial Silver.*

This ranks among the rich ores, as it contains 77—84 parts of silver to 23—26 of antimony in 100. Its specific gravity is 9.4—9.8; it is harder than calcareous spar, and is of a silvery tin-white color. When heated on charcoal it becomes converted into a brittle granule of antimonial silver, and, on continuing the heat, the antimony is all driven off in a white vapor, leaving the silver pure. It is somewhat brittle, a little ductile, and crystallizes in forms of the trimetric system (*pl.* 33, *fig.* 39), which are often grouped as in *fig.* 47. It is found in granular masses at Wolfach and Andreasberg.

2. *Antimonial Nickel.*

This consists of two equivalents of antimony and one of nickel. Its color is a light copper-red, running into violet; its fracture is uneven, small subconchoidal; it is harder than fluor-spar; it crystallizes in double six-sided pyramids (*pl.* 32, *fig.* 72), and in thin hexagonal plates. The principal locality is at Andreasberg in the Hartz.

Class 5. *Arsenids.*—Hausmann.

Combinations of arsenic with electro-positive metals. They are characterized, like the antimonids and tellurids, by giving out a white coating to the upper part of the glass tube within which they are heated, which is volatilized by additional heat, without melting. They give out, however, when heated on charcoal before the blowpipe, the peculiar garlic-like odor of arsenic.

1. *Copper Nickel.*

This is one of the most important of these combinations. It contains 34—40 per cent. of nickel, and may be used as an ore of this latter metal. It is of a bright copper-red color, to which it owes its name, and besides arsenic, also contains cobalt, iron, lead, antimony, and sulphur. It is found in

Saxony, Bohemia, Thuringia, Styria, Hungary, &c., associated with cobalt, silver, and copper.

2. *White Nickel.*

This, like the last, affords a workable proportion of nickel, containing 20—30 per cent. of this metal, with 71—73 of arsenic, and small quantities of cobalt, iron, copper, bismuth, and sulphur. It crystallizes mostly in cubes, with octahedral and rhombic-dodecahedral faces (*pl.* 33, *figs.* 36, 44, and 61). More rarely it is found in amorphous finely-granular masses. The ores of nickel have only recently become of importance, although the metal itself was discovered by Cronstedt in 1751. Its peculiarities, which assimilate it to the noble metals, have caused it in latter times to be much employed for various purposes. The metallic nickel is generally obtained from copper nickel, a name given this ore on account of its color, and for a long time considered an opprobrious epithet as long as it was found impossible to reduce it.

Nickel occurs almost always associated with cobalt, and both metals with arsenic, so that most cobalt ores are worked at the same time as well for their cobalt as the nickel which they contain. Nickel is of a silvery-white color, passing into steel grey; is very difficult of fusion, and heavier than iron. It is very malleable, and may be hammered into plates of one hundredth of an inch thick, and drawn into wire of one fifty-sixth of an inch in diameter. It may also be welded. It combines with several metals at a strong heat, and these alloys are employed practically in a great many ways. The most important of the combinations are known as white copper, German silver, argentine, packfong, and maillechort. The German silver used in the construction of knives and forks, consists of two parts of copper, one of nickel, and one of zinc. A mixture of five parts copper, two of nickel, and two of zinc, has nearly the color of silver, and is used for making knife handles, snuffers, gun mountings, philosophical apparatus, &c. For cutting out fine sheets, a mixture of three parts copper, one of nickel, and one of zinc, is best, as being most malleable. For castings, from two to three per cent. of lead must be added; and to obtain the most silvery-white color possible, the three metals must be melted together under a layer of charcoal powder, and a small quantity of iron added. This iron alloy is, however, much more difficult to work, on account of its brittleness. Care must be taken in using culinary and table articles constructed of German silver, that they be brought into contact with no corrosive liquids, as in addition to the poisonous effects of the essential metals, there is frequently a small proportion of arsenic still remaining in the nickel.

3. *White Cobalt or Smaltine.*

This mineral is of importance as an ore of metallic cobalt. It occurs in veins of primitive and transition rocks, associated with various other metals, as nickel, copper, iron, silver, and arsenic; in Saxony, Thuringia, Alsace, Spain, Hungary, &c. It is found in crystals belonging to the regular system, as cubes (*pl.* 33, *fig.* 35), rhombic dodecahedrons (*fig.* 30), and the combinations of these. It is also obtained in reticulated, ramified, and various other irregular and derivative shapes. It contains about twenty

per cent. of cobalt, and seventy-four of arsenic. Metallic cobalt, principally obtained from this arseniate of cobalt, is a refractory metal, similar to iron, and like it magnetic. The combinations of its oxydes form very valuable coloring matters, particularly for blue. To prepare these the ore must be freed from the arsenic, forming its larger portion, by roasting it in the air, the result of which is to drive off the arsenic in white fumes of arsenious acid. The resulting ore may be applied to many purposes. Thus it imparts a deep and beautiful blue to glass, for which it is much used. Melted with quartz it forms zaffre, safflor, or zaffra, used in the preparation of smalts. This is a glass formed from quartz and potash, colored by zaffre. The cobalt colors, known as Leitner's Blue and Thenard's Blue, are of great beauty. The first is obtained by calcining alumina with nitrate of cobalt; the latter by calcining alumina with phosphate of cobalt. Both remain unchanged in fire, for which reason they are applicable in painting porcelain and glass.

4. *Glance Cobalt.*

This mineral, like the last, is very rich in cobalt, for which reason it is much used in smalts works. It occurs in beautiful crystals of the regular system. The most common forms are shown in *pl.* 33, *figs.* 57, 61, 62, 50, 64, 60, 54, 55, 49, 58. It possesses a metallic lustre, is opake, with the fresh fracture of a silvery-white color, inclining to red, which soon overspreads the surface, and presents a beautiful play of metallic colors. It is brittle, and the fracture is uneven, somewhat conchoidal; when heated it gives off arsenious and sulphurous acid. It consists of 33.10 per cent. of cobalt, 43.46 of arsenic, 20.08 of sulphur, and 3.23 of iron. It occurs in veins and beds of primitive rocks in Norway, Sweden, and Alsace.

Class 6. *Selenids.*

The minerals of this class are combinations of selenium with electro-positive metals. They are readily recognised by the peculiar odor of burning selenium, when the substance to be tested is heated on charcoal before the blowpipe. A smell is developed, if selenium be present, similar to that of decaying horse-radish.

Selenium, when solid, is of a dark-brownish red color on the surface, the conchoidal fracture exhibiting a metallic leaden-grey tint. When in the finely divided state, obtained when reduced from the watery solution of selenious acid, it is of a vermilion red color. Thin splinters of compact selenium are somewhat transparent. It burns like sulphur, when heated, diffusing its characteristic odor, sensible even in very small quantity. In its general peculiarities and combinations it has much resemblance to sulphur. In and of itself it is of no practical importance; its combinations are some of them valuable for the metals they contain. The principal of these combinations are:

1. *Selenid of Silver.*

This mineral occurs in Mexico, and more rarely at Tilkerode in the

Hartz. It forms thin plates, which are rather pliant, and exhibits a cleavage into cubes. It is harder than rock salt, is opake, lustrous, iron-black, and contains from sixty-five to sixty-seven per cent. of silver.

2. *Selenid of Mercury and Lead.*

This remarkable mineral is exceedingly rare, and is found at Tilkerode and Lerbach in the Hartz. It occurs in finely granular, metalloid, bluish-grey streaks and spots, in a ferruginous calc spar, as shown by the dark portion in *pl.* 33, *fig.* 21. A third selenid, that of lead, occurs at Tilkerode, under similar circumstances. It is difficult to distinguish from the preceding, and furnishes a very argentiferous lead after reduction. It is, however, very rare.

Class 7. *Sulphurids, or Sulphurets.*

These are combinations of electro-positive metals with sulphur. They all yield the smell of sulphurous acid when heated before the blowpipe on charcoal; they are soluble in nitro-hydrochloric acid, with the separation of sulphur.

1. *Galena.*

Galena or sulphuret of lead is one of the most important of all minerals, furnishing the greater part of the lead of commerce, as also a considerable amount of silver. It occurs principally in veins, as in the Hartz, in Saxony, in Bohemia, France, England, and Spain. The most abundant deposits known are those in the north-western parts of the United States, Missouri, Iowa, Wisconsin, and Illinois. Galena is a combination of equal atomic weights of sulphur and lead, or of 104 equivalents of lead and 167 of sulphur, with a slight admixture of other sulphurets, as of silver, antimony, bismuth, copper, and iron. It most generally occurs in amorphous masses, which exhibit crystals in the cavities. The crystals belong to the monometric or regular system, the most usual forms being those of *pl.* 33, *figs.* 35, 33, 41, 43, 44; which, however, like most natural crystals, seldom or never occur in so perfect a form. It is more generally the case, that apart from incomplete development, the same crystal presents faces belonging to several different forms. The cube often appears incomplete or distorted, as shown in *fig.* 20. Other natural crystallizations are shown in *figs.* 11, 17, and 19. The crystals of galena, as well as the amorphous masses, tarnish on exposure to the air, exhibiting a dark bluish-grey hue; the fresh fracture is leaden-grey, and very lustrous. They have a three-fold cleavage, a piece of galena, when broken by a hammer, exhibiting the cubic character, as shown in *fig.* 6.

The specific gravity of galena is 7.58, its hardness being a little greater than that of rock salt. When heated, it breaks up, if struck with a hammer, into little cubes; at a high heat it melts and becomes converted into vapor, which is decomposed in the open air, with the formation of sulphate of lead; if this operation be conducted in closed vessels, the vapor condenses in crystals on the sides or colder parts of the furnace. These crystals present the appearance of imperfect cubes, as in *fig.* 8.

To obtain lead from its sulphuret, the latter is roasted in the open air, by which a great part of the sulphur is burned. The remainder, consisting of partially desulphuretted lead and sulphate of iron, is melted with charcoal and limestone. The lead thus obtained still contains the other metals which were originally mixed with it. It is called workable lead when in this state, and is, first of all, to be treated for silver. For this purpose it is brought into a cupellation furnace, so constructed, that a constant stream of air may pass over the melted metal. By this means the oxygen of the atmosphere coming in contact with it, converts it into oxyde of lead, which exhales to a considerable extent, but is principally drawn and let out through an adjoining aperture. The silver does not combine with the oxygen during this operation, and while the oxyde of lead or litharge is constantly being removed, the silver remains behind, until finally every particle of oxyde of lead has disappeared. The silver then undergoes a further preparation after being removed. The oxyde of lead is either sold in this form, as litharge, or it is melted afresh with charcoal, and reduced again to the metallic state.

Lead, on account of its malleability and readiness of fusion, its ease of working, and its great abundance, is one of the most important of all metals. Its oxydes and salts are also of extensive application. Litharge is used in glazing pottery and in the manufacture of glass; an addition of minium or red oxyde of lead, to melted glass, renders it transparent, and constitutes what is known as flint-glass, in contradistinction to crown-glass, into whose composition little or no lead enters. The glass used in porcelain painting, as also the pastes of the artificial gems, all contain a necessary proportion of oxyde of lead. Of the salts of lead, white lead is the most important. This is a carbonate of lead, or a carbonate combined with a hydrated oxyde. Acetate of lead, or sugar of lead, is used in dyeing, and in the preparation of many mineral colors.

2. *Vitreous Silver, or Silver Glance.*

This is a simple sulphuret of silver, and consists of 87.032 per cent. of silver and 12.968 of sulphur. It crystallizes in many-faced crystals of the regular system (*pl.* 33, *figs.* 30, 33, 35, 36, 45), and also occurs in reticulated, arborescent, filiform, and amorphous masses, as also in plates. It readily melts before the blowpipe, emits the odor of sulphurous acid gas, and leaves behind a button of silver. It occurs in veins, accompanying other ores of silver, and is not abundant except in Saxony, Bohemia, the Tyrol, Hungary, Spain, and Mexico. It is very remarkable in being a malleable ore, flattening out under the stamper.

In places where sulphuret of silver, native silver, and other rich silver ores occur, the metal is obtained by amalgamation. This consists in reducing the ore containing silver into a very finely divided condition, and in this state shaking it up with mercury; the mercury combines with the silver, forming an amalgam. Should sulphuret of silver be in question, it will be necessary first to drive off the sulphur by roasting the pounded ore with salt. During this operation the silver is converted into chloride of silver and metallic silver, which mixture is to be treated with water and

iron to remove the chlorine from the chloride, and to separate the silver in the metallic state. The residuum is then, as before remarked, to be agitated for a long time with mercury and iron in vessels, during which operation the amalgam is formed. After straining this amalgam, to separate the uncombined mercury, the residuum is placed in iron vessels and distilled. The mercury passes over in a sublimation, and the silver is left pure.

3. *Sulphuret of Copper and Copper Pyrites.*

The expressions, glance and pyrites, generally indicate combinations of sulphur. The copper pyrites forms an important ore from which to obtain the pure metal. It is a combination of simple sulphuret of copper with simple sulphuret of iron, and contains from thirty-two to thirty-four per cent. of copper. It is extensively distributed in veins and beds in primitive and transition rocks, being generally accompanied by galena. Copper pyrites has a brassy-yellow color, rather deeper than that of sulphuret of iron, and generally occurs in coarse masses, whose cavities present crystals belonging to the dimetric system, and exhibiting the faces of an acute (*pl.* 33, *fig.* 37), or an oblong (*fig.* 48), square octahedron. When roasted in the air its sulphur is converted into sulphurous acid, while the iron and copper oxydize, and combining with the sulphuric acid, form a soluble salt obtained by leaching the roasted mass. This salt is much used in the arts, being known as blue vitriol, containing green vitriol. This same double salt forms in mines by the gradual oxydation of copper pyrites, a considerable amount of which is dissolved in the waters of such mines. The salt is obtained from this solution, either by evaporation or by precipitating metallic copper by means of iron. The principal portion of the pyrites procured in mines is, after roasting, reduced to metallic copper. It is first melted with its flint matrix, by which means the oxydized iron is principally combined with the quartz, and converted into a slag, under which lies the copper combined with sulphur. This, after repeated roasting, is again melted with quartz sand and charcoal, and still more freed from iron, until finally an impure, sulphurous, and little ductile copper is found under the slag, mixed with the accompanying metals, lead, iron, arsenic, antimony, zinc, &c. This impure copper is purified by long-continued fusion in the melting furnace, in which the foreign admixtures are partly oxydized, partly driven off. The metal still requires additional preparation by being melted with charcoal before it will become perfectly malleable.

4. *Iron Pyrites.*

This is a sulphuret of iron which occurs extensively distributed, and in large quantity. It is found either crystallized or amorphous, in various rocks, clay slate, greenstone, hornblende, syenite, &c.; also in independent beds of considerable size, or in veins accompanying other ores. The crystallizations of pyrites are among the most perfect which occur in nature. *Pl.* 33, *fig.* 2, exhibits some single crystals from Chamouny: *a* is a cube distorted to a rectangular parallelopipedon; *b* is a pentagonal dodecahedron, whose pure crystalline shape would be that of *fig.* 57. *Fig.* 15 exhibits an agglomeration of cubes of pyrites lying between crystals of calcareous spar;

and *fig.* 22, a lump of crystallization of iron pyrites, like the preceding, drawn from nature. The crystals of pyrites which here appear in the simplest shapes of the regular system, exhibit other more complicated forms, as seen in *pl.* 33, *figs.* 33, 35, 41, 50, 54, 57, 60. The crystals as well as the amorphous masses, have a light brassy-yellow color. A remarkable variety of iron pyrites, which is of a whitish yellow color, and more easily decomposed by the air than the preceding, is the water pyrites. It is not different from the other in chemical composition, but crystallized in another system, namely, the trimetric.

Iron pyrites is a very useful mineral, although not applicable as an iron ore. It is rather used to furnish sulphur, and, in many places, the gold which is combined with it in small quantities pays well for its extraction. The pyrites is roasted, and the iron burnt to an oxyde, the sulphur to sulphuric acid. On leaching the mass, sulphate of iron is obtained, a salt of extensive application in the arts, under the name of green vitriol, or copperas. From the roasted green vitriol, fuming sulphuric acid, or the Nordhausen acid, is obtained. The residuum of oxyde is known in commerce as colcothar, and is used for coloring or polishing. Iron pyrites strikes fire with steel; and has, in certain cases, replaced flint for this purpose.

5. *Molybdenite, or Sulphuret of Molybdena.*

This is exhibited in foliated masses, composed of very thin, bluish grey, metalloid plates, unctuous to the touch like graphite. It occurs imbedded in granite and gneiss, in Sweden, Silesia, Hungary, France, Switzerland, the United States, and other places. It is found, generally, in the shape of bent leaves, between the constituents of granite, as shown in *pl.* 33, *fig.* 23. The metal forming the basis of this mineral has some very peculiar oxydes and salts, which are distinguished by their beautiful color, and are used by painters.

6. *Arsenical Pyrites.*

This mineral is distinguished for its remarkable crystalline forms. It is of a silvery white color, uneven fracture, and also occurs amorphous, granular, or homogeneous. On being heated it gives off metallic arsenic, leaving behind simple sulphuret of iron; for this reason it is very useful for the production of arsenic. It sometimes contains small quantities of silver and gold. The crystals of this mineral are rectangular octahedrons, single individuals often occurring of great perfection sprinkled in the general mass, as shown in *fig.* 18. It is found in beds and veins, in the primitive rocks, at Freiberg, the Hartz, in Bohemia, Cornwall, Sweden, and Hungary.

7. *Grey Copper Ore.*

Besides the preceding simple sulphurets, there are still a large number of more complicated combinations; among which this ore, or fahlerz, is conspicuous. This may be considered as a sulphuret of antimony, copper, and iron; in which combination, however, the antimony is sometimes partially or entirely replaced by arsenic, the iron by zinc, and in another variety by mercury: in the argentiferous ore, for the iron and copper, silver is partly substituted. This ore is sometimes found in remarkable

hemihedral crystallizations of the regular system. Thus there are tetrahedrons variously modified by faces of other forms of the same system. The most common forms of these crystals are seen in *figs.* 51, 52, 53, 56, 59. The tetrahedrons are often coated with a thin layer of copper pyrites, and then exhibit a beautiful golden lustre, these occurring at times of large size. The argentiferous grey copper ores are very valuable silver ores; that known as the *graugültigerz* contains 13–18 per cent., and the *weissgültigerz* nearly 31 per cent., of silver. The proportion of copper in this ore sometimes amounts to 30–40 per cent.; in the hydrargyrous ores the per-centage of copper is 34–36, and of mercury 2–8.

8. *Cinnabar.*

This splendid red mineral is a sulphuret of mercury, and is valuable as being the chief ore of mercury. It occurs crystallized, as in *pl.* 33, *fig.* 25, combined with carbon and alumina, as hepatic cinnabar or liver ore, or lamellar as in the coral ore. Its geological position is in grauwacke, and in transition sandstone and limestone; being found generally in beds, more rarely in veins. It is generally accompanied by calc-spar, native mercury, and amalgam. The mines of Almaden and Idria furnish the greatest quantity of cinnabar. Large mines have recently been opened in California. To obtain metallic mercury, this ore is heated in iron vessels, with iron or lime, by which the mercury is separated from the sulphur. Another process is to heat the cinnabar in furnaces so constructed that all the vapors generated are carried through long galleries, into chambers where they are condensed. Mercury and its ores are not generally distributed, and for this reason the metal bears a high price. It is used as a medicine, and also for coatings of glass mirrors: for many philosophical instruments, and for chemical investigations it is indispensable.

9. *Realgar and Orpiment.*

Both of these substances have already been mentioned under the head of arsenic as artificial products. The natural realgar occurs in earthy and amorphous masses, or in rhombic prisms (*fig.* 39). It is a bisulphuret of arsenic, and possesses an aurora-red color, with tolerable transparency. Native orpiment is a tersulphuret of arsenic, is of a fiery yellow color, and is used in painting and dyeing, as also as an addition to lead in the manufacture of shot.

Class 8. *Oxydes.*

Combinations of oxygen with electro-positive metals.

1. *Oxyde of Iron.*

Of all minerals embraced in the class of oxydes, that of iron is unquestionably the most important. It is diffused over the whole earth, and is the principal material from which metallic iron is procured. It occurs in various forms, and is a constituent in all rocks, and in most minerals. Oxyde of iron, in and for itself, and in combination with water, forms several distinct minerals. Thus, crystallized peroxyde of iron forms specular iron. This occurs in very perfect crystals of metallic lustre, and occasionally splendent.

It is opake, black, and hyacinth-red, with slight translucency in the laminæ. It is brittle, and its fracture is conchoidal. When pure, specular oxyde is an unmixed oxyde of iron, containing 69.34 per cent. of iron, and 70.66 of oxygen. Its crystals have an acute rhombohedron (*pl.* 34, *fig.* 30) as the primary shape, and occur generally with planes of derivative forms (*figs.* 23, 25, 31, and 40). Specular oxyde of iron occurs also in aggregations of highly lamellar irregularly curved leaves, of a shining black color, known as micaceous iron ore: *pl.* 34, *fig.* 1, represents a mineral coated with this micaceous ore.

A second form of oxyde of iron is more important on account of the greater masses in which it is found. This is the hematite ore. Red hematite occurs, like specular iron ore, in beds and veins in the older rocks, particularly in clay slate, mica slate, gneiss, and granite; also in transition rocks in clay slate, and in grauwacke. Hematite is of a steel-grey, cherry-red, brownish, and blood-red color, and occurs under the most diversified circumstances of distribution. The purer hematites are frequently of a highly fibrous texture, and reniform or kidney-shaped (*fig.* 20). It is sometimes found in cylindrical scaly masses, as in *fig.* 11, as also amorphous, dull, earthy, and, in the latter form, mixed with various rocks. With clay it forms red ochre, and with common limestone, the calcareous iron ore. Not less important are the brown and yellow iron ores. These are combinations of oxyde of iron with water, and furnish excellent ores for reduction. *Fig.* 9 exhibits a form of fibrous brown hematite, such as is frequently found in the Hartz, and *fig.* 5, another variety of its occurrence. The iron ores among which the oxydes are pre-eminent, always contain a considerable proportion of their gangue or matrix. The manufacture of iron from its ore consists of two distinct operations, the mechanical separation of extraneous matters, as far as possible, and the reduction of the oxyde to the metallic state. The iron ore is introduced in alternate layers with coal into a furnace several stories high, into the lower part of which a powerful blast is continually kept up by a blowing apparatus. By this means the contents of the furnace are brought to, and kept at, a white heat. At this temperature the oxygen of the iron combines with the carbon of the coal, and forms carbonic oxyde and acid, the iron being left in a metallic state. The accompanying rock is melted by adding the necessary flux. In this way the whole contents of the furnace become perfectly liquid, the iron, from its greater density, occupying the lower part. By making certain apertures in the clay stopping up the bottom of the furnace, either the slag or the melted iron may be drawn off.

The iron thus obtained is still very impure, and contains especially a good deal of carbon in the state of carburet of iron; it is now known as cast iron or pig iron. This pig metal is purified by remelting in a melting, or run out furnace; after which it is puddled, and hammered out into bars in forges. Bar iron still contains carbon, the amount not over one half per cent., and not materially affecting its malleable properties. On the other hand, a slight per-centage of phosphorus (also of silicon, according to some authorities) renders the iron cold short; and the presence of sulphur, arsenic,

and copper, renders it red short. Iron, of all ductile metals, is the hardest and toughest; it cannot be hammered out into very thin plates without breaking, but on the other hand it may be drawn out into very thin wire. Purified and melted iron has a specific gravity of 7.79, common bar iron of 7.788. It melts at from 2822 to 2876° F.; and volatilizes in the flame of the oxy-hydrogen blowpipe, and in the heat produced by the galvanic battery. Steel, one of the principal products of iron, consists of a similar, but more intimate, combination of iron with carbon. The amount of carbon in steel varies according to the kind from 0.5 to 1.5 per cent.; and iron with this per centage of carbon acquires the property of hardening when rapidly cooled.

2. *Silica.*

Silica or silicic acid, since it possesses the distinguishing properties of an acid, is a combination of oxygen with a simple substance, silicon, only obtainable by the delicate manipulation of the chemist. It is diffused in vast quantity over the earth. It occurs, in a very pure state, both crystalline and amorphous, and forms combinations with all fixed oxydes. The purest crystalline silex or silica is found in rock crystals. These occur in perfect single crystals of the hexagonal system, as double six-sided pyramids (*pl.* 34, *fig.* 36), or as regular hexagonal prisms with six-sided pyramidal terminations (*fig.* 51), or as derivatives from these forms, *fs.* 21, 22, 45, 72. Rock crystal frequently occurs in small crystals, more rarely several feet in length. Quartz, a common form of crystallized silex, and often somewhat impure, is well known to all miners; and in the most beautiful specimens presents somewhat the appearance of *figs.* 2 and 3. Rock crystal and quartz pass from perfect transparency into an opake milky white, and with foreign admixtures into every color of the rainbow. Besides the crystallized varieties of silica, there are others, as chalcedony, remarkable for their beauty and hardness, and indispensable in the manufacture of various instruments and utensils. The crystallized varieties are used as gems, and excellent lenses are obtained from perfectly transparent and colorless rock crystal. Quartz, either compact, or as sand, is a principal ingredient in glass; chalcedony and agate are converted into ornaments, polishing instruments, scale beds, mortars, &c. In sand we find one of the most important constituents of the fruitful soils; and finally all building materials, whether stone or brick, owe their solidity to the mortar of which this same sand is a most important ingredient.

3. *Tin Ore.*

Tin ore is the oxyde of tin, and at the same time the source from which most of the metallic tin of commerce is derived. It occurs in primitive rocks, in veins or beds; traversing granite, gneiss, mica slate, and clay slate. Tin is not very generally diffused, and occurs in large quantity in but few localities, especially in Bohemia, Saxony, Cornwall in England, and in the East Indies, in Malacca, and Banca. The ore is sometimes found in remarkable crystals of the dimetric system; it is semi-transparent or opake, and of various colors, as white, grey, red, brown, or black. *Pl.* 34, *fig.* 8, represents a group of crystals drawn from nature, and *fig.* 19 a mass of

granite imbedding similar crystals. The forms here represented are modifications and twin formations of the forms, *figs.* 29, 37, 42. This substance is a very valuable ore of tin, containing as much as 78 per cent. of the pure metal. In reducing the ore it is pounded fine, and roasted. By this means, a portion of its impurities is dissipated, especially arsenic and sulphur; others being converted into lighter substances which can be separated from the heavier tin by washing. The residuum is then to be heated with charcoal in the furnace, in the usual manner. The raw tin, thus obtained, is very impure, containing in addition lead, bismuth, arsenic, iron, antimony, and zinc. It is purified by the application of a gentle heat, during which the purer tin runs off, leaving a portion behind mixed with impurities. The best and purest tin is the Malacca, Banca, and English grain tin. After this comes the common English grain tin, then the English block tin, and the Bohemian and Saxony mountain tin. The applications of tin are very numerous. It is cast into various shapes, converted into different culinary utensils; covering sheets of iron plate it forms the material used by the tinner; mixed with mercury it constitutes the amalgam coating the backs of looking-glasses, &c.

4. *Rutile and Anatase.*

Both minerals contain the same oxyde, resembling the oxyde of tin in many respects. The metal obtained from them, titanium, is the only one of a red color besides copper. Neither mineral is abundant, the principal localities being Norway, Spain, France, Hungary, and Switzerland, where they occur in primitive rocks. Several localities in the United States are known where rutile is found. *Pl.* 34, *fig.* 10, represents a group of rutile crystals drawn from nature, while *figs.* 28, 43, 53, give its theoretical forms; *figs.* 29 and 32 represent the crystalline form of anatase. The oxyde forming these minerals is an acid of titanium, called titanic acid.

5. *Pyrolusite, Braunite, Manganite, Hausmannite.*

These are all oxydes of a metal, manganese, similar in its properties to iron. Hausmannite is a red oxyde of manganese, and occurs crystallized, in shapes of *figs.* 29 and 32; pyrolusite is oxyde of manganese, its crystal forms as in *figs.* 26, 28, 29; manganite is hydrated sesquioxyde of manganese, and crystallizes in shapes whose primary form is a rhombic prism (*fig.* 24); braunite is anhydrous sesquioxyde of manganese, crystallized like manganite, and accompanying it. Crystals of both occur together, as at Ilefeld, in beautiful masses, as shown from nature in *fig.* 7. These oxydes also occur amorphous, as coatings of other minerals. Pyrolusite and manganite are used in the manufacture of oxygen, which may be procured by simple heating of these minerals; their further applications in the arts are numerous. They are used in glass works to decolorize glass, the bottle-green color of common glass disappearing entirely by the addition of pyrolusite; an increased proportion of the mineral produces a beautiful red in melted glass, which, by the addition of oxyde of tin, becomes converted into a flesh-color, used in the painting of porcelain and glass. The metal manganese has been converted to no useful purpose, owing to the difficulty of separating it from its ores.

6. *Sapphire, Ruby, and Corundum.*

These beautiful gems are oxydes of aluminium, a silvery-white metal, and in chemical composition do not differ from the purest common clay, being rather its crystallization, modified by slight admixtures. The forms of the crystals are those of *pl.* 34, *figs.* 30, 36, 38. The most transparent blue crystallized variety is called sapphire, the yellow crystals are called oriental topaz, and the transparent red variety, oriental ruby. The less transparent kinds, of different colors, of green, blue, red, and greyish, are all grouped together under the general name of corundum. The transparent varieties occur in single, frequently rounded, crystals and grains, in river beds, and in alluvial soils, especially in Ceylon, China, France, and Bohemia. Corundum is found in primary formations in Switzerland, North America, Sweden, the East Indies, and China. Red corundum is the ruby, which is often more highly valued than the diamond. Sapphires are very costly gems, and are generally cut like the diamond. Rubies of eight grains are worth from $200 to $250; the most esteemed sapphires of a dark-blue and pure color, are worth from $350 to $400 for a weight of twenty-four grains; the paler, of sixteen grains' weight, $25 to $30. The sapphire, ruby, and corundum, are the hardest stones after the diamond.

7. *Arsenious Acid.*

This has already been referred to under the head of arsenic. The most common forms of the crystals are the tetrahedron (*fig.* 39) and the octahedron (*fig.* 40). It frequently accompanies rocks containing arsenic. It is nearly allied to the following minerals:

8. *White Antimony.*

This is an oxyde of antimony, corresponding to the last mineral, and occurs in crystals, whose form is represented in *pl.* 34, *fig.* 50. It accompanies the ores of antimony, and especially grey antimony.

9. *Red Copper Ore.*

This is an oxyde of copper occurring in beautiful crystallizations of the regular system, as in *figs.* 27, 33, 43, 44, 61, 64. It is of a cochineal red color, passing into bluish grey, possesses an uneven conchoidal fracture, and an adamantine lustre on a very smooth surface. The finest crystals have been found in Cornwall, in Siberia, and at Chessy near Lyons, in primitive and transition rocks.

Class 9. *Silicates.*

Besides the simple oxydes just mentioned, there occur in nature a large number of their combinations, amongst which, those of different oxydes with silica (the silicates) are by far the most numerous. They are known before the blowpipe by their decomposition by the salt of phosphorus, a useful test, the silica being set free, and the base uniting with the free acid of the salt of phosphorus. The variety of silicates is very great, as will subsequently be shown.

1. *Datholite.*

Datholite is a combination of silicate of lime with borate of lime and water,

or a boro-silicate of lime. It is eminent for the beauty and perfection of its crystals. It is found in great abundance at Andreasberg, in compact greenstone, traversed by veins of compact dolerite, and having crystals of the mineral in its cavities; also in New Jersey, Connecticut, and the Michigan copper region. It crystallizes in the monoclinic system, its forms being the oblique rhombic prism (*pl.* 34, *fig.* 73) and its derivatives. *Fig.* 6 is a group of datholite crystals from nature. This is a rare mineral, and of no practical application.

2. *Apophyllite.*

Apophyllite is one of the most beautiful minerals in nature. It occurs in veins and beds in primitive and amygdaloidal rocks in the Tyrol, Bohemia, the Hartz, Scotland, Greenland, Mexico, and North America. Its most usual crystal forms are represented in *figs.* 28, 37, 43. It sometimes occurs in crystals of various sizes, grouped together (*fig.* 17), the individuals forming acute square octahedrons. It is transparent, colorless; or else, white, yellow, green, and rarely rose-red. The crystals have a very perfect cleavage in the direction of the basal plane, from which the mass may be diminished by sections, perpendicular to the main axis, producing square faces. The basal corners are almost always replaced by rhombic faces, striated in the direction of the primary axis. Apophyllite is silicate of alumina combined with silicate of potash.

3. *Olivine, or Chrysolite.*

This mineral is a silicate of magnesia with a slight admixture of protoxyde of iron, and rarely oxydes of manganese, chromium, nickel, copper, and tin. Olivine is widely diffused in small crystalline granules, and occurs in the cavities of most basalt. The larger crystals (or the noble olivine) are found in Bohemia and in Hungary, and are used for ornamental purposes. Chrysolite occurs of a green, brown, or red color. The crystals belong to the trimetric system, as in *pl.* 34, *fig.* 74.

4. *Picrosmine.*

This is a hydrous bisilicate of magnesia with a slight admixture of protoxyde of iron, and manganese, with a small amount of alumina; it occurs in a single deposit in Bohemia. It is opake, sub-transparent at the edges, iridescent, and of a vitreous lustre, and of various shades of green. From its cleavage, its crystallizations belong to the form of *fig.* 41.

5. *Chondrotite.*

This mineral, a silicate of magnesia, is found in New Jersey and elsewhere in the United States, in Finland, &c. It is transparent or translucent, of yellow, brown, reddish-yellow, green, or black color; and generally occurs in granules. When heated it loses color, becoming, first black, and then white. Its crystallization is that of *pl.* 34, *fig.* 54, or monoclinic.

6. *Augite, or Pyroxene.*

This occurs finely crystallized in volcanic mountains, and in lavas, and forms an essential constituent of basalt and dolorite. It is dark green, brown, and black, sometimes light green and white, with a vitreous or resinous lustre, opake, or only translucent at the edges. The crystals

belong to the monoclinic system, and present principally the forms of *pl.* 34, *figs.* 35, 52, 67. Augite, which is a silicate of lime and magnesia, contains often likewise alumina, protoxyde of iron, and protoxyde of manganese.

7. *Hornblende.*

Hornblende is widely distributed in certain rocks, which it characterizes, and in an imperfectly crystallized state is fibrous and somewhat radiated. Like the preceding, it belongs to the monoclinic system, and *fig.* 75 represents its primary form. It differs from the preceding in containing less lime, but more magnesia and silica, being, like it, colored by the protoxydes of iron and manganese; it sometimes, in addition, contains alumina, fluor, and water. Hornblende occurs of various colors, grey, white, greenish, dark green to black, and also in various modifications. A variety of hornblende, consisting of very long, closely compacted, and interlaced crystals, frequently occurs in gneiss, mica slate, and limestone. *Fig.* 13 represents this variety of gneiss.

8. *Staurotide.*

Alumina combined with silex forms an extensive series of minerals, and in this species is frequently replaced, to a greater or less extent, by other minerals. In staurotide, for instance, a portion of the alumina is constantly replaced by protoxyde of iron. It occurs imbedded in gneiss and mica slate; the crystals belonging to the trimetric system (*pl.* 34, *figs.* 47, 70).

9. *Andalusite* (disilicate of alumina).

This mineral affords fine crystallizations of the trimetric system. *Fig.* 12 represents a mass of crystals of andalusite in granite. The crystals are right rhombic prisms.

10. *Kyanite* (disilicate of alumina).

The chemical composition of this mineral approximates it to the last; its crystals, however, belong to the triclinic system (*pl.* 34, *fig.* 65). Kyanite is often of a vitreous lustre, on the sometimes striated surface; the fracture is iridescent; the color sky blue, sometimes white. It occurs usually in bladed crystallizations, in mica slate, gneiss, dolorite, and limestone; it is rarely found amorphous.

11. *Topaz* (fluo-silicate of alumina).

Topaz is distinguished for its hardness. It exceeds quartz in this respect, and occurs imbedded, in very perfect crystals of the trimetric system, in gneiss and granite. It is found in great beauty and large quantity, in the topaz rock of Schneckenstein, in Saxony. The crystals from this locality have generally the appearance presented in *pl.* 35, *fig.* 9. Its composition may be set down at two thirds silicate of alumina, with fluo-silicic acid.

12. *Humboldtite* (silicate of alumina and lime).

This mineral is found on Mount Vesuvius. It crystallizes in shapes of the square system. It is very hard and scratches glass, has a yellow color varying to green, and melts before the blowpipe into a vesicular sub-transparent glass. Its crystalline form is shown in *pl.* 34, *fig.* 55.

13. *Mica* (compound silicate of alumina).

The common or bi-axial mica crystallizes according to the monoclinic system. A second variety, which is distinguished for its optical properties, and which crystallizes according to the hexagonal system (*fig.* 69), is the uni-axial mica. The common bi-axial mica is a very useful mineral. Its crystals are nearly regular rhombic plates, belonging to an oblique rhombic prism as the primary form. It exhibits the most perfect cleavage of all minerals, being capable of splitting into exceedingly thin leaves. It is used for window panes, and covers for microscopic objects, and is very useful in the cultivation of microscopic water plants. It occurs, in large leaves, in Siberia, and also in New Hampshire; and in general forms a constituent of all granite, embracing in its composition, silica, alumina, potassa, manganese, and fluoric acid.

14. *Euclase* (compound silicate of alumina).

This exceedingly rare mineral occurs in Brazil, crystallized according to the monoclinic system (*fig.* 58). It is transparent, of a vitreous lustre, mountain green, passing into white and blue; brittle.

15. *Idocrase* (compound silicate of alumina).

This mineral occurs in very perfect crystals of the dimetric system (*figs.* 53, 48), with a vitreous or resinous lustre, sometimes striated on the surface. It is semi-transparent, brown, or of various shades of green. It consists of silica, alumina, oxydes of manganese and of iron, and lime. It was first found in the ancient lavas of Vesuvius; more recently, in other places.

16. *Garnet* (compound silicate of alumina).

Garnet, of which there are many varieties, presents itself in very perfect crystallizations of the regular system. The form shown in *pl.* 34, *figs.* 33 and 64, as also the rhombic dodecahedron (*fig.* 61), are especially prevalent. The faces of the crystals possess a vitreous lustre, are pearly smooth, or partly striated or rough. The colors are exceedingly various, being red, ferruginous, brown, yellow, black, white, and green (*pl.* 35, *fig.* 6). The transparency is either perfect, imperfect, or wanting entirely. The most remarkable varieties are the noble, the Bohemian, and the oriental garnet or almandine, of a beautiful cherry-red, blood-red, or brownish-red color, occurring in crystalline rocks, in gneiss, and chlorite slate. Another kind much esteemed is the pyrope, of a blood-red color, occurring in loose grains in clay near Bilin in Bohemia. Other varieties are colophonite, grossular, &c.

17. *Beryl* (silicate of alumina and glucina).

The noble beryl, or emerald, is a bluish-green or green gem. The most valuable crystals are found in Peru. Those of four grains are worth from twenty to twenty-five dollars; of twenty-four grains, from five hundred and fifty to six hundred dollars. The crystallized forms belong to the hexagonal system. The most frequent of these are shown in *pl.* 34, *figs.* 22, 49, 57, 67, 68, 69. A less important variety is found in beryls of a green, blue, and yellow color, either transparent or opake. Opake beryls are not rare, and occur sometimes very perfect in granite, as shown in *pl.* 35, *fig.* 15, a sketch drawn from nature.

Beryls of great beauty are found in the granite of Mertschinsk, as also in the Ural and Altai mountains, and near Rio Janeiro. Beryls of enormous size occur in the United States. One specimen from New Hampshire weighs 240lbs., and is four feet in length. The lateral faces of well-formed crystals of beryl are generally striated vertically. In its composition it consists of a combination of silicate of glucina with silicate of alumina.

18. *Prehnite* (silicate of alumina and lime).

This mineral occurs in volcanic and primary rocks in the Tyrol, Piedmont, Carinthia, Salzburg, Sweden, Norway, and the United States. Its crystals belong to the trimetric system, and are derivatives of the forms in *fig.* 62, *pl.* 34. Prehnite generally occurs in rhombic prisms; it is also found granular, foliated columnar, and amorphous. It is a combination of silicate of alumina with silicate of lime, and water.

19. *Nepheline.*

Nepheline, a variety of which is called *elaeolite*, occurs both amorphous and crystallized: its crystals belong to the hexagonal system. It is transparent or translucent, of conchoidal to splintery fracture, generally of an oil-green color, but is sometimes blue, red, and brown. It consists of silicate of alumina, silicate of potash, and silicate of soda.

20. *Scapolite and Wernerite.*

The first named mineral bodies, besides lime and alumina, contain a small quantity of potassa and soda, wanting in Wernerite. Both are colored by a slight admixture of oxydes, especially of iron. Both crystallize in the dimetric system. Scapolite occurs in forms like *fig.* 46; Wernerite like *fig.* 53, *pl.* 34. Scapolite occurs in the volcanic rocks of Vesuvius, and is abundant in some crystalline rocks, especially granular limestone, occurring in many places in the United States; Wernerite in Sweden, Norway, Finland, and various parts of the United States.

21. *Iolite, or Dichroite.*

This mineral is remarkable for its color, which, in one position, appears indigo-blue, and at right angles to this, yellow or brown. It occurs amorphous and crystallized, the crystals belonging to the trimetric system (*pl.* 34, *fig.* 71). They are found imbedded in granite. It thus occurs in Sweden, Norway, Finland, and in the Northern United States. It is sometimes polished, and used as a gem.

22. *Thomsonite.*

This mineral is met with in Scotland, both amorphous and crystallized, The crystals belong to the dimetric system (*fig.* 50), have a smooth surface, vitreous lustre, and white color. They are more or less translucent to transparent. This mineral consists of silicates of lime, soda, and alumina, with water.

23. *Natrolite.*

Natrolite occurs both amorphous and crystallized, and sometimes forms a very beautiful mineral of a white, whitish-yellow, or reddish color. Its crystallizations are often globular forms covered with fine needle-shaped crystals (*pl.* 35, *fig.* 4). They belong to the trimetric system (*pl.* 34, *fig.* 59). Natrolite, in addition to soda, alumina, and silica, contains water, and

a small quantity of oxyde of iron and lime. It occurs in the Tyrol and Rhineland, being not very rare, especially in basaltic and volcanic rocks.

24. *Leucite* (disilicate of potassa and alumina).

This mineral is known by the form of its crystals, the shape shown in *fig.* 64, deriving from it the name of leucitohedron. It occurs in volcanic masses, as in the neighborhood of Rome and Vesuvius. It is generally of a grey color, and its crystals frequently exhibit considerable size and perfection.

25. *Analcime* (disilicate of soda and alumina).

Analcime is a hydrated silicate of soda and alumina. Its crystals are shaped like those of the preceding, and occur generally in hemispherical white crystals, as in the Tyrol, or in small transparent crystals of one or two lines in diameter, as shown in *fig.* 15, from the clay slate of Andreasberg in the Hartz.

26. *Chabazite* (silicate of soda, lime, potassa, and alumina) *pl.* 34 *fig.* 18.

Chabazite is a hydrated silicate whose crystals belong to the hexagonal system (*figs.* 65 and 66.) It is semi-transparent, or translucent, of conchoidal fracture, and brittle. *Stilbite* and *heulandite* are minerals allied to chabazite in chemical composition, consisting of lime, alumina, silica, and water. The crystals are highly pearly rectangular prisms, belonging to the trimetric system. *Fig.* 14, *pl.* 34, is taken from an Andreasberg specimen. *Mesotype* (*fig.* 16) and *epistilbite* (*fig.* 63) are allied minerals.

27. *Tourmaline.*

Common tourmaline, as it occurs in granite in the Hartz, is represented in *fig.* 4, *pl.* 34. This mineral is of great interest, owing to the optical and electrical properties of many of its varieties. The primary form of the tourmaline is an obtuse rhombohedron (*fig.* 34), under modifications of which the tourmalines occur of considerable size. The constitution of tourmaline is frequently very complex; it generally contains soda, lime, manganese, iron, alumina, silica, and boracic acid.

28. *Harmotome.*

This mineral exhibits very interesting forms of twin crystals. *Pl.* 35, *fig.* 5, illustrates a specimen from Andreasberg. The crystals are right rectangular prisms, terminated by square octahedron faces; of these crystals, four unite at right angles, forming a cross. These sometimes unite at angles of 90°. This rare mineral consists of silicates of alumina and baryta, with water, potash, and lime.

29. *Albite* (disilicate of soda and alumina).

Albite or soda feldspar forms a component of many rocks, occurring in Siberia, in very large crystals. Their primary form is an oblique rhomboidal prism (*pl.* 34, *fig.* 65). Albite is generally of a white or grey, yellow, and red color; lustre vitreous; iridescent on the cleavage surface; lateral faces frequently striated.

30. *Feldspar.*

Of all silicates, feldspar is the most important, as well as most generally diffused. It forms a constituent of many rocks, and consists of silicates of potassa and alumina; it crystallizes in forms of the monoclinic system

(*figs.* 75 and 76, or *pl.* 35, *fig.* 26). Complete crystals possess not unfrequently a twin structure, as shown in *fig.* 2, *pl.* 35. Feldspar is readily cleft in two directions, the surfaces thus exposed being lustrous. Its fracture is conchoidal, uneven; color white, to flesh color. The white, yellow, flesh colored, or ferruginous portions of granite, are feldspar, which, with quartz and mica, compose this extensively distributed and important rock. The feldspar of granite decomposes surely though slowly; and its potassa, combining with water and silica, becomes a principal source to plants of this essential inorganic constituent. The rest of the feldspar, richer in alumina, and poorer in silicic acid and potassa, is also an important item in the soil; alumina being essential in rendering a sandy soil fruitful. Kaolin is also decomposed feldspar, and is found abundantly in granite. Feldspar is closely allied to the preceding mineral, namely, albite, when a portion of its potassa is replaced by soda, as in *pericline.* Closely allied to feldspar are *oligoclase* and *spodumene,* the latter containing lithia in place of potassa. *Pl.* 35, *fig.* 1, represents a specimen in granite from the island Utö. *Labradorite,* in which lime and soda replace potassa, belongs also to the feldspars.

Class 10. *Salts.*

The minerals belonging to this class are non-silicious combinations of an acid with oxydes; from which an acid may be derived by boiling with caustic potassa, or by melting with carbonate of soda; or which exhibit an effervescence of carbonic acid gas when exposed to the action of certain acids.

1. *Carbonate of Lime.*

Carbonate of lime is one of the most important of all minerals: it is a constituent of many rock-formations; is dissolved in all waters in the form of a bicarbonate; and as such, in combination with other acids found in the soil, enters as a necessary ingredient into the organism of plants and animals. Water containing carbonate of lime in solution is capable of dissolving fresh carbonate of lime, especially under pressure; such as would be produced on the lower end of a spring of water, in coming from a considerable depth below the surface. The pressure removed, and the water exposed to the concentrating influence of atmospheric evaporation, the necessary excess of lime will be deposited, in a crust, on all bodies wet by the fluid. Where, as in caverns, such water drops continually from a certain point, a deposit of carbonate of lime will be left behind, and will accumulate in time so as to form a considerable mass, resembling an icicle in shape. Such formations are called stalactites; and the less regular deposit of the same carbonate, which usually forms beneath the stalactite, is called stalagmite. *Fig.* 13, *pl.* 35, represents the initiatory stage in the formation of such stalactites, where the rock has become covered with a coating of stalactital matter, with depending projections. *Fig.* 23 represents a stalactite after it has attained its characteristic form.

Carbonate of lime is the actual constituent of limestone, chalk, and

muschelkalk; it forms a principal portion of wood ashes, and the bones of animals, into which it is introduced by water holding it in solution. When crystallized it is known as calcareous spar. Calcareous spar has the most diversified crystallization to be met with in the mineral kingdom. It is likewise one of the dimorphous substances, or those whose forms do not all belong to the same system. Calcareous spar is consequently distinguished as *arragonite,* and as *calcareous spar proper.* In the former the crystals belong to the trimetric system (*figs.* 34 and 35). The crystals are right rhombic prisms, and are often grouped together, as in *fig.* 18. In the latter, or calc spar proper, the crystals belong to the hexagonal system. The forms are derived from the holohedral primary form of the double six-sided pyramid, or from a rhombohedron in which the angle is 105° 5′, some of which are represented in *pl.* 35, *figs.* 27, 29, 32, and 36. The hexagonal prisms are frequently pure, and such crystals often form very fine specimens, as in *pl.* 35, *figs.* 8, 16^a, 16^b; they are often terminated by the faces of the double six-sided pyramid, as shown by *figs.* 36, 45, and 47. Rhombohedral crystals, particularly secondary rhombohedrons, are also very common, together with various combinations of surfaces of rhombohedrons with those of six-sided prisms and pyramids. *Fig.* 20 represents a druse of rhombohedral segments (*fig.* 17) of dogtooth spar, with the very interesting crystal form of *fig.* 43, or the scalenohedron (scalene dodecahedron). The principal forms of crystallization of calc spar are shown in *pl.* 35, *figs.* 25, 28, 33, 37, 40, 41, 44, 45, 46, 47, 49, and *pl.* 36, *fig.* 37. In *pl.* 35, *figs.* 10, 11, 14, 21, 22, 24, and *pl.* 36, *fig.* 29, may be seen druses with many of the different modifications. *Pl.* 35, *fig.* 19, represents the hexagonal prism, with a finely crystalline coating of a second crystallization on the first, as a bed. The variety, *pl.* 36, *fig.* 3, is called double spar.

2. *Carbonate of Iron.*

This mineral is often found associated with carbonate of lime, carbonate of magnesia, carbonate of manganese, and receives various names in its different modifications of constitution and form. The primary form of its crystallization is an obtuse rhombohedron: it also occurs in various secondary derivative forms. *Pl.* 35, *fig.* 3, represents a variety from Steinheim, called *Sphærosiderite,* a carbonate of iron of spheroidal form and radiated texture. *Spathic iron* is the usual name of the pure carbonate of iron; it often contains some carbonate of magnesia and lime. It occurs in vast beds, and yields an iron excellent for conversion into steel. Its crystals are shown in *pl.* 36, *fig.* 36, having the obtuse rhombohedron as their primary form. Spathic iron also occurs in crystal druses of the character seen in *figs.* 6 and 14. By increasing the proportion of lime and magnesia, to a degree sufficient to form *dolomite,* we have *brown spar.* The crystals of this have a very great similarity to those of simple calcareous spar; they are, however, readily recognisable, by becoming brown when exposed to the weather, owing to the manganese and iron they contain.

3. *Carbonate of Strontia.*

This is met with in the form of strontianite, in no great abundance, and

crystallized nearly like arragonite. The crystals occupy either the hollow of the druse (*pl.* 36, *fig.* 7), or present themselves in superficially radiating needles (*fig.* 20).

4. *Carbonate of Lead.*

The white lead of the arts is a carbonate of lead. This substance is found native, though rarely, in acicular, fibrous, distorted prisms, of the trimetric system (*pl.* 36, *figs.* 47 and 48); *fig.* 21 represents a druse of this *white lead ore.*

5. *Boracite.*

This is a biborate of magnesia found at Lüneburg and Segeberg, in very fine crystals, associated with anhydrite (*pl.* 35, *fig.* 12). The most usual forms of the Lüneburg boracite are the rhombic dodecahedron (*pl.* 35, *fig.* 48), and their transitions into octahedrons (*fig.* 42) and rhombic dodecahedrons, with cubic and octahedral surfaces (*fig.* 30). The cube is also found with angles truncated or replaced (*figs.* 38, 39), but the opposite solid angles differ in their modifications. The crystals are imbedded in anhydrite.

6. *Sulphate of Lime*

This compound of sulphuric acid and lime constitutes, at times, whole beds of rocks, specially in connexion with rock salt. Without the water of crystallization, sulphate of lime is known as *anhydrite* or *karstenite.* In this form it occurs in amorphous masses (*pl.* 36, *fig.* 31), traversed or not by crystallized anhydrite, and is of a greyish-white, bluish, or blackish color. Combined with water of crystallization sulphate of lime forms *gypsum* or *plaster of Paris.* When gypsum is ground into an impalpable powder, and strongly heated in an iron vessel over a fire, its water of crystallization will be given off in the form of bubbles, rising through the powder, presenting a strong resemblance to ebullition. This, indeed, is technically termed "boiling." This anhydrous powder, when mixed with water, will, by taking up a portion of the latter, soon harden, taking the shape of any form or mould into which the mixture may be poured. For this reason it has extensive applications in the arts. The unheated powder, if mixed up by means of a solution of carbonate of potassa, possesses the same property of fixing or hardening.

7. *Sulphate of Baryta.*

The crystallized forms of this substance have the rectangular octahedron for their base. It received the name of *barytes*, or *heavy spar*, from its great specific gravity, by which it may readily be distinguished from all other minerals, excepting ores. The most common among the manifold crystallizations of barytes are shown in *figs.* 1, 2, 4, 6, 8, 9, 10, 13. It is generally of a white, or bluish-white color, and very abundant in some localities. It is used, when ground up, to adulterate white lead.

8. *Vitriols.*

By the term vitriols miners understand the sulphates which are formed by the exposure of sulphurets to the weather, and become dissolved in the waters of the mines. Iron, or *green vitriol* (*fig.* 27), with its most common crystallized form (*fig.* 45), is sulphate of iron: it is of a green color, becoming ferruginous on exposure to the air from the formation of an

oxyde. This substance is also known under the name of *copperas*. Copper or *blue vitriol* is also well known, this crystallizing in the form of *figs.* 34 and 35, *pl.* 36, and in crusts as in *fig.* 19. It is of a beautiful blue color, and, with the preceding, is much used in dyeing: *white vitriol*, the sulphate of zinc, is also used in the arts. It occurs in very decomposable prisms (*fig.* 23) of the trimetric system. The crystals are sometimes as in *fig.* 42.

9. *Fluor-spar* (fluoride of calcium).

This beautiful mineral is extensively distributed, and may be used for various purposes of ornament. From it is obtained fluoric acid, which may be used for etching glass. A druse of fluor is represented in *pl.* 36, *fig.* 32.

10. *Wolfram* (tungstate of iron and manganese).

This mineral is found in the gneiss of Bohemia and Saxony, in the form of large black striated crystals, with a lustrous surface (*pl.* 36, *fig.* 15).

11. *Yellow lead ore* (molybdate of lead).

This, associated with ores of lead and zinc, occurs, in beds and veins, in various parts of Germany, Hungary, Mexico, and North America. It crystallizes in variously modified square octahedrons, and occurs, as in *fig.* 22, finely crystallized, and in dirty yellow masses.

12. *Pyromorphate*, or green lead ore.

This is a phosphate of lead containing some chloride of lead. It is found in Bohemia and Saxony, is of a pistachio-green color, and sometimes occurs in small green crystals of the hexagonal system, strewed as it were over the surfaces of other minerals. *Fig.* 10 represents a specimen from Zellerfeld.

13. *Wavellite.*

This substance (shown in *pl.* 36, *fig.* 5) occurs in concentric radiated crystallized groups. It is a phosphate of alumina, and not very abundant.

14. *Rock salt.*

Rock salt constitutes vast subterranean beds, which yield their contents either to actual mining operations, or by solution in salt springs. This salt or chloride of sodium crystallizes in cubes, which are generally distorted into rectangular parallelopipedons (*fig.* 30). In itself it is colorless, but often variously tinged by bitumen. Salt springs may be made to yield their solid contents by the evaporation of their waters. This evaporation may be brought about by boiling, or by exposure to the sun in shallow pans. In some places the stream of salt water is permitted to run for a long distance through a dense thorn hedge. In this way a considerable evaporation is effected by the extended surface exposed to the air. The water is also obtained in a purer form, as the other constituents of the spring, especially the gypsum, dissolved in all such waters, are, to a great extent, separated by the evaporation, and the thorns coated so as to present the appearance seen in *pl.* 36, *fig.* 11. The crystals in which the salt is separated from its solution by boiling are mostly incomplete cubes, generally with more or less perfect square funnel-shaped cavities.

15. *Sulphates of the alkalies.*

The three most common alkalies, or their combinations with sulphur, form very important constituents of the soil. These sulphates are those of soda, of potassa, and of ammonia, all of which are well known as artificial

products. The two latter have the same primary form of crystallization, namely, that of *figs.* 33 and 40, belonging to the trimetric system; sulphate of soda, on the other hand, crystallizes in the monoclinic system; *pl.* 36, *fig.* 18, represents crystals of sulphate of ammonia; *fig.* 28, of sulphate of potassa; and *fig.* 17, of sulphate of soda.

16. *Alum.*

This well known substance, a sulphate of alumina and potassa, is produced by the decomposition of alum slate, and forms in minute crystals on the surface. By leaching earth containing alum, and evaporating the ley, the salt may be obtained in very large masses of crystals, whose primary form is the regular octahedron (*fig.* 24). Octahedral segments (*fig.* 25) in groups, as shown in *fig.* 16, are, however, more frequently met with.

17. *Borax* (borate of soda).

This substance is used as a flux in melting various metals and solders, and is applied to various other technical purposes. It is met with in a crude state as *tincal*, obtained in lumps from certain lakes in Thibet and Persia. The refined borax is obtained from tincal by repeated crystallization, producing variously modified rhombic prisms.

18. *Saltpetres of potassa and soda.*

The ammonia which forms in the ground by the decomposition of various substances containing nitrogen, and diffused in damp air, becomes converted into nitric acid by contact with porous solid bodies, as limestone; the acid then combines with the bases existing in the soil. Thus the Chilian saltpetre is obtained by the saturation of this nitric acid by soda, this nitrate of soda crystallizing in obtuse rhombohedrons (*fig.* 36), and occurring in vast quantities, efflorescing from the surface of the ground, in South America. Common saltpetre arises in a similar manner by the conversion of the potassa of the soil into a nitrate. This does not occur naturally in large masses, but is prepared by artificial processes of decomposition. This saltpetre crystallizes in the trimetric system, with primary forms, as in *figs.* 47 and 48, as also in the modifications (*figs.* 41 and 43). Its crystals are generally hexagonal, with two acute terminations (*fig.* 26).

19. *Phosphates of alkalies.*

These also are essential to the fertility of a productive soil, although occurring always in small quantities. Phosphate of potassa, as obtained by evaporation from its aqueous solution, crystallizes dimetrically (*fig.* 42): phosphate of soda, on the other hand, is monoclinic, and generally in modified shapes, the primary forms being represented in *pl.* 36, *figs.* 38, 39, 44, 46, and 49.

Economical Uses of Minerals.

In comparing the different groups of minerals just described, we find a great diversity in regard to their economical value. The utility of single minerals does not always depend on the properties which render a mineral substance fit for a certain end, but rather is based on the degree to which it

abounds. A large number of silicates would be of great value if found in vast quantities. The same also is true of the metals. Platinum, considering its properties, would be the most valuable metal for the most varied technical applications, did it only occur as abundantly as iron. Hence also it follows that our idea of the value of a mineral does not always express its utility. Limiting ourselves to well known species, we find single minerals of the first group, the metalloids, of very general utility; of this, sulphur is an illustration. Even the rare variety of carbon, the diamond, is indispensable in glass-working; and on its employment as an ornamental gem is based a special branch of art, namely, diamond grinding, which is carried on in England and Holland. While the diamond is the hardest of all bodies, so its working is the most difficult. The hardness of the diamond exceeds that of other minerals so much, that no substance but its own dust can be used in grinding it. In grinding diamonds horizontal metal disks are used, which are made to rotate with immense velocity by means of a lathe. The diamond to be ground is cemented fast to a stem of wood or brass. The metal wheel is coated with oil, and strewn with the powder of impure or very small diamonds. Even the chips and fragments of the larger diamonds obtained are brought into use for the same purpose by pounding them in a steel mortar. After the wheel has been properly adjusted, the diamond is so fixed by means of the stem to which it has been cemented, that a certain part to be ground shall press upon the wheel, which is then to be set in motion. In this operation the diamond powder becomes finer, and the diamond is worn away by the attrition. After one face has been properly ground, the diamond is fixed in another position, and the operation thus repeated until the cutting is completed. Simple contrivances are adopted for so holding the diamond, with its stem, that it may be ground at any angle required.

The forms produced by grinding the diamond are the brilliant and the rosette or rose (*pl.* 32, *figs.* 85, 87, 90, 84, and 91). The object of giving so many facets to the diamond is to increase its sparkling, the light being reflected in all directions from the great number of variously inclined faces.

The groups which succeed the metalloids, as the native metals, the tellurids, antimonids, arsenids, sulphurets, and selenids, are all valuable on account of the metals to be obtained from them. The native metals are mixtures of various metallic substances. Native gold, for instance, always contains silver; native platinum almost always includes with it iridium, osmium, rhodium, palladium, ruthenium, iron, and manganese. The other groups contain ores of metals. A metal is found in chemical combination with a metalloid, as sulphur, selenium, tellurium, arsenic, and antimony. Economical purposes, therefore, require that the native metals, which are nearly all of the precious class, be separated from these various mixtures, and that all the components be preserved. In the other classes, on the other hand, the metal is generally preserved at the expense of the metalloid, which is mostly lost. All of these, excepting silver, belong to the baser metals. The separation of the noble metals is generally effected by solution and precipitation of the individual species from the solution. The

manufacture of silver, and of the baser metals, is effected at the mining establishment, and depends principally on the separation of those substances which give to the ore its distinguishing feature. Thus from the arsenids we obtain the combined metal, silver for instance, by roasting the ore: this drives off the arsenic in the form of vapor of arsenious acid. Sulphur is dissipated in the same way; and the processes by which a separation from injurious combinations is effected, are sometimes so complicated as to form a considerable portion of the occupation of the workers in metals.

Of the oxydes some are important as being ores from which their metals may be economically obtained. Thus iron is obtained from its oxydes, or from minerals rich in this latter substance. Not less important is silica, in its different varieties. All our different forms of glass are combinations of silica with powerful bases, especially with potassa and soda. By the combination of impure carbonate of potassa, impure silica, and a certain quantity of lime, we obtain the well known green bottle and window glass. White window glass is obtained in the same way, by the addition of some decolorizing agent which shall remove the green color produced by the presence of protoxyde of iron. Peroxyde of manganese is used for this purpose, as by it the protoxyde of iron may be changed into peroxyde: this, when in large quantity, gives the glass a yellow color, but in less amount scarcely tinges it at all. For the better sorts of glass, only the purest materials are used, the silica, for instance, being furnished by the quartz rock, which contains it in great purity. By the addition of oxyde of lead the glass becomes more fluid, and such easily melted glass is used for preparing the colors for glass and porcelain painting, by melting with it various metallic oxydes. Thus, by the addition of oxyde of cobalt we get a dark blue glass, by that of oxyde of copper one of a beautiful reddish brown, which is pounded and rubbed to a fine powder. This powder, mixed with a drying oil, is applied to the glass or porcelain surface to be painted. After the paint has somewhat dried, the objects to which it is applied are exposed to a red heat, which melts the glass into an enamel.

Besides the application of silica in the manufacture of glass, no less important is the use made of several of its natural combinations. Porcelain is obtained by strongly heating together alumina, an alkali, and silica; for this purpose a substance of native occurrence is employed, namely, the kaolin or porcelain earth, which is found in large quantities at various localities. Perfectly clear and colorless rock crystal is used for purposes of ornament. Some colored varieties of silica, as the amethyst, are also applied to the same purpose. Chalcedony and agates also consist essentially of silica, handsomely colored by various oxydes; they furnish an excellent material for many instruments on account of their great hardness. Thus, plates of agate are used to suspend the knife-edges of delicate balances; the pivot holes of magnetic needles are also made of this same material, to avoid undue friction. Valuable dishes and capsules, mortars for chemical purposes, and many other useful implements of art, are constructed of these substances.

Some of the silicates constitute minerals of great value. The most

important are those belonging to the family of feldspar. Feldspar is an essential ingredient of entire rocks, as granite and gneiss; minerals allied to this are important constituents also of other rocks, as labradorite and syenite. Feldspathic minerals, as constituents of the soil, are of the utmost value. Most of them disintegrate readily under atmospheric influences, and yield up to the plants in the soil those inorganic ingredients so necessary to their growth.

On examining certain minerals, as granites, which are rich in feldspar, we shall find that they gradually lose their compactness by exposure to the weather, crumbling into a fine sand. On investigation this is found to be rich in alumina and poor in alkali. In all probability it is the mechanical agency of the water, with the unceasing alternations of temperature, together with the dissolving action of the carbonic acid contained in the water, that wears away the stone; the carbonic acid also extracts the stronger bases, and thus contributes, in a great measure, to the disintegration of the rock. It is also to be observed, that the silica, in the condition in which it is separated from alkaline silicates, by aqueous influence, is very soluble; also, that the feldspar, with its alkalies, communicates to water a proportion of that dissolved silica so necessary to the sustenance of certain plants, especially the grasses, and which is deposited in their tissues. It has already been mentioned that purer beds of feldspar furnish, in many localities, by their decomposition, masses of the finer porcelain earth or kaolin. And it is not only this naturally-formed kaolin that is made use of in the manufacture of different kinds of porcelain and stone-ware; the mixtures of the constituents must frequently be varied. Thus, in the manufacture of porcelain, the coarser qualities of feldspar are ground, and mixed up with the finer porcelain earth, in the proportions required for the particular kind of ware.

The class of the salts is no less important. Carbonate of lime, in the form of limestone, furnishes an excellent building material, and is one of the most important constituents of a fertile soil. Besides this general utility of carbonate of lime, certain varieties, forming entire rocks, find valuable applications. The granular crystalline form of compact carbonate of lime is known as marble, the different varieties being produced by the fineness of the grains, or the varying character and distribution of the coloring matters. The coarse blocks of marble, after being extracted from the quarries, are taken to marble works, and there cut up into slabs and other forms, by means of broad saw-like steel blades, stretched in frames. The lithographic stone, used so extensively at the present time, is also a carbonate of lime. Chalk is another of these carbonates of lime, differing, however, from the rest mentioned, in consisting largely of the calcareous shells of minute infusoria and other animals, thus more nearly related to the muschelkalk. Many useful applications of carbonate of lime depend on the circumstance that the carbonic acid is driven off at a strong red heat, the lime retaking the acid from the atmosphere when exposed to the latter. Burnt or quick lime, when water is poured over it, takes up a certain amount, forming a definite chemical combination, a hydrate of lime, which,

with an additional quantity of water, forms mortar. The hydrate loses its water in the air, passing slowly and by degrees into a carbonate again, and thus hardens into a mass resembling the original limestone in compactness.

Sulphate of lime is also used for many purposes. In the form of karstenite, or *anhydrite*, it is used as a building material. Anhydrite becomes gradually converted into gypsum by the action of the atmosphere, gypsum being a combination of water and sulphate of lime. In the native mass gypsum is known as alabaster, and on account of its softness may be applied to various purposes.

The vitriols are used in coloring. Green vitriol, with tannic acid, furnishes the black color, ink; blue vitriol is used for similar purposes; a third salt of sulphuric acid, used in dyeing, is alum. Its value, like that of most salts of alumina, consists in its being a good mordant, that is, it forms permanent combinations with the fibre of many fabrics; the color being firmly combined with the alum, is indissolubly united to the cloth. The fabric intended to be dyed may be first steeped in the alum solution, before the application of the coloring matter, or both may be applied together. The uses of rock salt, or common cooking salt, are well known. Saltpetre, as well that of soda as of potassa, is the single substance yielding nitric acid. This is distilled in glass retorts, with sulphuric acid, by which the nitric acid is expelled and driven over into large glass reservoirs. Nitric acid is indispensable in the separation of metals, as gold from silver; its uses in other departments of the arts are manifold. Vast quantities of saltpetre are used in the manufacture of gunpowder, this consisting of saltpetre, sulphur, and charcoal. It is also used to advantage in pickling and curing meat. Borax is valuable as a flux for metals, as also for purifying the metals from oxydes. It also furnishes various borates of importance. Borate of lead forms the medium by which gold is applied to porcelain in the operation of gilding this ware.

The alkaline sulphates are used both in the arts and in medicine. Sulphate of soda, obtained from salt works and sea water, as also in the manufacture of soda, constitutes what is known as *Glauber Salts*.

GEOGNOSY AND GEOLOGY.

PLATES 37—53.

THE inanimate objects of our planet may be considered from two points of view, either in respect to their mathematical and physical properties, and chemical compositions, as individuals, or as forming parts of a whole, combined according to certain definite conditions.

The science which treats of the inorganic components of our earth, from the first point of view, is that of *Mineralogy, or Anorganology*, while *Geology* has reference to the second mode of their consideration. Like astronomy, geology affords most sublime and elevated subjects of contemplation; and like it also, it has made astonishing progress within the last few decades.

Geology is properly included under geography; since by the latter, in its wider sense, we must understand the entire physical history and structure of the globe.

Inanimate nature is presented to us under three points of view corresponding to the three conditions in which matter is aggregated: namely, as gaseous (the atmosphere), as liquid (the waters), and as solid (the land or solid portions). According to this difference in the aggregation of inorganic matter, we have the following divisions of geology:

1. *Atmosphærology, or Meteorology.*
2. *Hydrology.*
3. *Mineralogical Geology*, or geology in its restricted sense.

Like every other branch of the philosophy of nature, geology (in the above limited meaning) may be treated of in two ways, descriptively and historically. Hence the further subdivision into the descriptive portion, *Geognosy*, and the historical portion, *Geogeny*, or *Geology* in its most narrow signification. Geognosy furnishes us with ascertained and established facts, upon which, as a foundation, the theoretical superstructure of geogeny is reared. Hence it is evident that a study of the former must precede that of the latter; since it is only by the combination and comparison of facts, that logical conclusions and satisfactory theories become possible. Geognosy might then be understood as the account of the present peculiarities of the solid parts of the earth; but when we remember that our knowledge of the earth extends only to exceedingly minute depths compared with her entire radius, it were more modest in us to define geognosy as the account of the earth's crust. It is to mining operations, particularly, that we owe our knowledge of this portion of the earth: at least it was this branch of art that first led us to the knowledge of certain laws of her structure. It is,

however, not the only means which has enabled us to become acquainted with the lower regions of the earth's crust: we shall see subsequently, how certain conditions of stratification reveal to us structures and relations at depths which it might be impossible for us, otherwise, to ascertain. Just as geogeny requires geognosy as a necessary foundation, so does geognosy require mineralogy; since it is aggregations of simple minerals, either separately or in combination, that constitute the earth's crust. It is not all mineral substances that are prominent in this respect, by far the greater number are not brought into view; it is proportionably very few that present themselves as important constituents of rocks. Of these few, some constitute entire formations singly; others form large masses, only in combination with each other, or with the preceding. These different combinations, as well as the simpler mineral forms, all constitute a whole, geognostically speaking, to which we give the name of *rocks*. It is thus evident, that a mineral may occur as a rock, but that every rock must not necessarily be a simple mineral. Just as a mineral is compounded of simple elements, these being combined according to the rules of chemical affinity, so minerals may be compounded into rocks; the force influencing them, however, is not chemical affinity, but cohesion. Furthermore, as the ingredients of mineral bodies stand, to a certain extent, in necessary combinations, this may only be incidental in regard to the constituents of rocks. These rocks may be considered in respect to their mineralogical composition, or with regard to the relation in which they stand to each other. The first brings them under the head of *Petrography* or *Lithology*, the latter under that of *Oreography*. Petrography treats of rocks in the minute, oreography in the great, or as constituting formations. The former bears somewhat the same relation to the latter, that mineralogy does to geognosy: the study of petrography must therefore precede that of oreography, in a philosophical examination of the entire subject.

From what has already been said, it follows that rocks may be divided into simple or homogeneous, and mixed or heterogeneous; yet, however distinct the two ideas may be, it is sometimes difficult to say, to which kind a certain rock must be referred. The compact varieties of the heterogeneous rocks sometimes present so intimate a mixture of ingredients, that at first sight they may not be seen in their true characters. The homogeneous are connected with the heterogeneous, by the most insensible transitions; as the heterogeneous are with each other. Thus what petrography loses in respect to the elementary variety of her forms, she more than makes up by the infinite diversity of their combinations.

There is no special difficulty in determining rocks when they present themselves in their characteristic forms; the proper appreciation of many transitions of one rock into another, can, however, in many cases, only be effected by means of the help afforded us by Oreography. It is, nevertheless, of the highest interest and importance to geologists to have an accurate knowledge of such transition forms, as they sometimes reveal to us very interesting affinities, or at least analogies between different formations.

As before remarked, only a few minerals occupy a prominent position in

respect to geognosy; and the interesting generalization has been made that all such belong to the class of the oxygenids (the class characterized by oxygen combinations). These bodies, so important in geognosy, are the following:

1. *Quartz*, or crystallized silicic acid (silex), with the impure varieties, hornstone, silicious shale, jasper, and whetstone slate.
2. *Mica*, or micaceous bodies, with the nearly allied chlorite, and talc.
3. *Feldspar*, or feldspathic minerals (among which we distinguish feldspar proper or orthoclase), labradorite, saussurite, albite, and oligoclase.
4. *Amphiboles*, as hornblende.
5. *Pyroxenes*, as augite, diallage, and hypersthene.
6. *Calcareous*, including the pure and impure formations, limestone, marl, tufa, &c.
7. *Dolomite*, or carbonate of lime combined with carbonate of magnesia.
8. *Gypsum*, hydrated sulphate of lime.
9. *Karstenite* (anhydrite), anhydrous sulphate of lime.

I. GENERAL PETROGRAPHY.

The first part of geognosy or petrography teaches us the character of rocks or formations, and arranges them in systematic groups. Let us now turn our attention for a moment to this subject. Considering the rocks in a genetical point of view, they naturally fall under two heads; first, *isonomic*, or those which were produced by a simultaneous crystallization or deposition from an aqueous or igneous liquid; and secondly, *heteronomic*, those which are composed of materials evidently formed at different times, or in different localities. These appear to have been brought together by subsequent agencies, and their parts stand entirely in accidental combination.

All the parts of a rock, whether isonomic or heteronomic, must stand in actual combination. Considering the case of granite, which consists of a crystalline granular mixture of feldspar, quartz, and mica, we are enabled to assume that these three minerals, in actual combination, are the result of a simultaneous (not to take this term too literally) crystallization from a melted mass. Granite must therefore be counted among the isonomic formations. The same is the case with regard to syenite, the different porphyries, &c. The expression simultaneous cannot be taken literally, since in the gradual cooling of the liquid matter of the different minerals, all could not crystallize at the same instant of time, owing to the difference in their points of congelation: one must harden first, and the other occupy its interstices. By simultaneously, therefore, we understand a certain period, during which the force of crystallization, or the congelation and separation of amorphous masses, was continually acting. Limestone, which in many cases is amorphous, is also to be counted among the isonomic rocks, since its formation was also brought about by a simultaneous deposition of its particles. The case is different with the heteronomic rocks, in which we

must suppose one ingredient to have been completely formed before another was added to it, and forced by accidental agencies into a combination. Examples of heteronomic rocks are afforded by sandstone, grauwacke, and various other conglomerates. Conglomerates consist of two principal portions, one combining, and the other combined. The portion combined is that which we suppose to have been completely formed: it generally presents the appearance of fragments of different isonomic rocks, rounded by water into pebbles of various sizes. The combining portion is an earthy, finer substance, cementing the first into a compact mass. This is accordingly termed the cement. The following survey of the petrographical system will, it is hoped, serve to render the distinctions between isonomic and heteronomic rocks more intelligible, as well as to introduce the subject of Oreography, which is to be treated of subsequently.

II. SPECIAL PETROGRAPHY.

A. Isonomic Rocks.

These present themselves to us under various conditions, and it is a matter of great interest to study the connexion between the different formation stages, and the probable or certain origin of rocks. With respect to the origin of many rocks we know little or nothing; as regards others, such as those which we see forming under our own eyes, we can speak with entire confidence. We need only refer to the lavas which burst forth as molten masses from the bowels of the earth, or to the different deposits from waters. Analogies, such as are of common occurrence, must furnish the key to those rocks with regard to whose formation we cannot speak with positive certainty. Take porphyry as an illustration, a rock in whose imperfectly crystalline, or entirely amorphous substance, we often find single crystallized particles, and even the most beautiful individual crystals. Analogies to this character are to be found in many processes of art. If melted glass be cooled very slowly, it is not a rare occurrence for single crystals to separate in the compact amorphous mass; and a similar phenomenon is observed in the slags produced in different metallurgical operations. The same is the case with respect to lavas in those parts of a lava current where a gradual cooling has taken place. When we find precisely the same circumstances in the older rocks, why may we not ascribe them to a similar, if not actually identical cause? When we see that during an exceedingly slow cooling of a vitreous slag, a crystalline granular solid is produced, possessing the same texture as many plutonic rocks, why are we not entitled to conclude that the latter have been produced in a similar manner?

The principal distinctions to be made, with respect to the variety of crystallization of isonomic rocks, are the perfectly crystalline, the semi-crystalline, and the imperfectly crystalline. These modifications occur

both in homogeneous and heterogeneous rocks. In amorphism we distinguished the earthy, opaline, and vitreous. Genetically considered, the opaline bodies appear to have been produced by the gradual solidification of a gelatinous matter; the vitreous, by the rapid cooling of a melted mass.

Order 1st. Silicious Rocks.

This order embraces the rocks in which silex forms the principal ingredient: we may divide it into three sections.

Section 1. *Quartz Rocks;* including:

Quartz rock proper; with its modifications, the compact, the granular, and the slaty quartz. Compact quartz rock is of a splintery fracture; the granular approximates closely to quartz sandstone, in fact it is difficult to draw the line of distinction. Here also belongs the silicious frit, which is nothing else than an incomplete melting together, or agglutination of quartz sand. It occurs in the vicinity of volcanic masses, to whose influence it owes its origin. The slaty texture of the last modification, the slaty quartz rock, is to be ascribed to mica, whose crystalline laminæ, lying in the same plane successively, thus permit a separation. The remarkable part performed by the mica, in this way, will be referred to more fully hereafter, many rocks deriving from it the property of splitting in definite directions. When quartz rock, which is generally of a light color, acquires a darker tint by the addition of oxyde of iron and manganese, aluminous matter, &c., it passes into:

Argillaceous quartz rock, to which also belongs *silicious slate,* a combination of crystalline and amorphous silex, with clay slate. This is distinguished into a common, with splintery, and a jaspery, with conchoidal fracture. Its color is generally black, although sometimes occurring grey, green, or brown. It frequently contains anthracite, and it is to carbon in this form that silicious slate probably owes its black color. Silex traverses it in veins, always of a white color, the carbon of the rock never penetrating these veins. Calcareous spar also occurs in veins in a similar manner.

Jasper. This is an intimate combination of silex with a little alumina: generally colored brown by iron. It rarely occupies an extended place among rocks, being quite restricted in its occurrence. It sometimes incloses crystals of feldspar, in which case it becomes porphyritic. It passes into whetstone, and silicious shale. It has frequently a strong resemblance to a burnt clay in the so called porcelain jasper, a clay baked by igneous action. The banded jasper is a variety exhibiting layers of different color.

Section 2. *Hornstone.*

The rocks belonging under this head consist of an intimate combination of quartz and compact feldspar. The principal of these is the hornstone rock, whose most remarkable transitions are into quartz rock, and a compact feldspar rock called whitestone. An increase in the quantity of

the quartz carries it into the former; a diminution of quartz, into the latter. The quartz is generally the common splintery kind, rarely waxy; the feldspathic material is more compact, rarely sparry. The predominating color is grey of various shades.

Section 3. *Silicious Porphyry.*

Silicious porphyry, as the name indicates, is a silicious mass, in which feldspathic crystals are interspersed. The principal varieties are:

Quartz Porphyry; of rare occurrence, and only found in Sweden. The general color is white, as are also the crystals of feldspar.

Hornstone Porphyry. This is often very similar to the preceding, but readily distinguishable by a simple blowpipe test. While quartz porphyry forms only a frit in the blowpipe flame, this melts, without much difficulty, into a white enamel. Its colors are grey, brown, yellowish; and in the mass thus constituted, crystals of feldspar are readily distinguishable.

Silicious Porphyritic-slate. This beautiful rock is rather rare. In masses of jaspery, silicious slate, lie feldspathic crystals of a light color. This rock readily passes into hornstone.

Jaspery Porphyry. This consists of feldspar crystals lying in a matrix of earthy jasper; and is of a lavender blue, grey, and greenish color.

Order 2. *Micaceous Rocks.*

The rocks of this order derive their name from containing mica, or chlorite and talc, which are closely allied to mica. Chlorite and talc may either replace or accompany mica. In the first series (the micas), mica and its allies occur pure and distinct.

Section 1. *Micas.*

Mica. It is principally the biaxial mica that occurs as a rock; the uni-axial being but rarely met with. It is a little remarkable, that where mica occurs in very large quantity, the laminæ are never of very large size. It splits up into very thin plates, these consisting of minute scales of mica combined into layers. Its color is generally brown running into black, rarely silvery white.

Chlorite. This is met with under different forms, namely, as chlorite slate, as chlorite rock, and as potstone.

Chlorite slate is the well known schistose chlorite of the mineralogist Its colors are seldom lively, passing from dark-green into greenish-grey. Chlorite rock is represented by common chlorite, which is generally coarsely slaty, and readily passes into potstone, which is an intimate combination of chlorite and talc. This potstone is not unimportant in a technical point of view, serving not only as a material for the most important utensils of some nations, but also admitting of conversion into various shapes by the art of the turner.

Talc. The talcose slate of mineralogists generally exhibits a green, yellow, or white color. It passes, on the one hand, into chlorite and talc; on the other, into steatite.

Section 2. Clay Slate.

The rocks of this section present an intimate union of talc, mica, or chlorite, with quartz and feldspar. The micaceous minerals predominate; and mica slate, a combination of the common biaxial mica with quartz, is the rock of this series which is most abundant. Those modifications which contain chlorite and talc occur but rarely.

Clay Slate. This tends towards chlorite, towards mica, and towards talc. in proportion as it contains a superabundance of any one of these three substances. Its laminated structure is very distinct, and there are few rocks which are as well calculated for a satisfactory study of all the laws of lamination as this. Large plane tabular, and very thin layers, which often traverse whole mountain masses, alternate with those of the most remarkable complication of folding and contortion.

The common clay slate, containing mica in superabundance, and of a grey color, often contains carbonaceous matter, which imparts a black color; oxyde of iron communicates a red, or reddish-brown tint. When the materials are very intimately combined, only a feeble glimmering will be observed; when this combination is less thorough, the scales of mica will be very evident on the surface of thin laminæ, and produce some lustre. Chlorite slate betrays itself by its greenish color, communicated by the chlorite. A calcareous variety is of a clear yellow, blue, or greenish-white color, often covered by a ferruginous tinge.

The transitions of clay slate are very various: the principal are into whetstone, silicious, and grauwacke slate, and hearthstone.

Roofing Slate. This is nothing more than clay slate penetrated by carbonaceous or bituminous particles. The principal external peculiarities exhibited by clay slate are found in this variety also. When exposed for a long time to the air, it becomes covered with a white crust, caused by the disappearance of the carbonaceous matter. The rock is very lustrous on the planes of lamination. Nearly allied to it is—

Graphite Slate, an intimate mixture of clay slate with graphite. It possesses a metallic shining lustre, caused by the graphite contained in it in plates.

Alum Slate. This is an intimate combination of clay slate with iron pyrites, thoroughly penetrated by coaly or bituminous matters. From the former it derives a black, from the latter a brown color. The brown varieties burn with a flame. Alum slate is a substance not without its importance in the arts, as it furnishes, in a great measure, much of the material for the fabrication of alum. The iron pyrites contained in it undergoes oxydation, owing to the fine and divided state in which it occurs. Both the iron and the sulphur of the pyrites combining with oxygen, a sulphate of iron or green vitriol is formed. This is decomposed again, and the sulphuric acid combines with the alumina and potassa of the alum slate, forming alum. For this reason, that portion of the bed of alum slate exposed to the atmosphere, soon becomes coated with a white crust, which consists of coarse alum. Bituminous alum shale is especially adapted to the manufacture of alum, as it not only furnishes as good a material as the black, but from its combustibility may be used for fuel.

Calcareous Clay Slate, an intimate admixture of carbonate of lime and clay slate. It is a valuable rock, furnishing excellent materials for soils. While common clay slate does not act very favorably on vegetation, this variety permits the finest forest growth. It is of a dark color, for which reason it is put to a very peculiar use in some countries. This consists in sprinkling it, when crumbled into pieces, on snow-covered ground, thus accelerating the melting of the snow, at the same time that an useful manure is added to the soil.

Section 3. *Horn Slate* (Hornschiefer).

This section contains only one rock, horn slate. It is a tough solid substance, and is often a great hindrance in mining. Hornblende often enters into the more usual combination of mica and quartz, and communicates to the usual grey or dusky black color, a tinge of green.

Section 4. *Flagstone* (Gestellstein).

These are rocks consisting of a crystalline schistose mixture of micaceous minerals with quartz. First to be mentioned is :

Flagstone. In the mixture just referred to, mica is the prevailing component; chlorite and talc occur more rarely. As any one of these three mineral substances occurs combined with quartz, we have micaceous, chloritic, and talcose flagstone. The lamination of flagstone is very distinct. The quartz granules are generally invisible, being concealed by the mica. These quartz grains often occur in lumps, and form entire beds by their combinations; the micaceous matter investing these lumps produces a knotty undulating lamination. The color of the rock depends on that of the mica. The chlorite flagstones are generally green, the talcose, white.

Hornblende-, graphite-, marble-, dolomite-flagstone, schorl- and *micaceous-iron slate,* are rocks belonging in this place : they are distinguished from each other by the proportion in which one or other of the above-mentioned ingredients enters into its composition ; this taking place frequently in such quantity, that the micaceous substance is entirely displaced.

Section 5. *Gneiss.*

This section is composed of rocks which consist of micaceous substances, quartz, and feldspar, and possess a decidedly crystalline laminated structure. The first species to be mentioned, is

Common Gneiss. The mica is arranged in parallel layers, imparting to the rock its schistose structure ; color grey, brown, and black : the quartz is generally grey, and in no great proportion, and is even sometimes entirely wanting. The colors of the feldspar are mostly grey and white, the red is rare. Similar modifications are found in gneiss to those in flagstone, effected by the micaceous element. Thus we have a chlorite, or a talc gneiss, as chlorite, or talc, replaces the mica. On account of the solidity of gneiss, it is much used for building and other similar purposes. Hornblende is sometimes added to the other constituents of gneiss, thus producing *hornblende-gneiss.* The micaceous element is sometimes entirely displaced by the hornblende.

Order 3. *Feldspathic Rocks.*

Feldspathic minerals form the constituents of these rocks. Common feldspar itself, or orthoclase, most generally constitutes this ingredient; in rarer cases, the vitreous feldspar or sunadin, as also the compact feldspar. These feldspathic substances may be replaced by their allies, albite and oligoclase. Quartz and mica are generally united with feldspar, sometimes so intimately that the mixture can scarcely be distinguished from a chemical combination.

Section 1. *Granite.*

Granite, that well known and important rock, is a mixture of feldspathic and micaceous minerals with quartz. It is one of the most interesting rocks, both on account of the great number of its modifications, and the wide extent to which it prevails. Its color is very variable, depending upon whether the predominant feldspathic matter be flesh-color, greyish-white, or greenish; the quartz transparent, milk-white, grey, rose-red, or sapphire; the micaceous matter brown or silver white; or whether the mica be replaced by chlorite or talc. The two latter minerals often occur combined, forming what is distinguished by many geologists as protogine. Granite has the same general composition as gneiss, feldspar predominating in the former, mica in the latter. The principal difference lies in their different modes of occurrence; and genetically considered, the two rocks have an entirely different formation. Gneiss has always a decided lamination or stratification, which is rarely seen in granite, and then in an entirely different manner. The grain of granite is present under all its modifications; it may be large and coarse, or small and finely granular; and while in the latter the different minerals can no longer be distinguished by the naked eye, in the former each constituent particle appears to occupy an almost independent position. In the coarse-grained granite, the mica, for instance, is sometimes found in plates which are more than a foot square. Granite is especially favorable to cultivation: decomposing readily, it furnishes many inorganic matters of vast importance. Feldspar, in whatever combination it may be met with, readily decomposes under the influence of water, heat, &c., and after single soluble constituents have been removed, it then forms kaolin or porcelain clay. Granite is a very valuable building material, and is of importance in the manufacture of porcelain and glass.

Syenite. This may be considered as a granite, in which hornblende occupies the place of mica. For this reason it is sometimes called hornblende-granite. Mount Sinai, a name associated with all the traditions of our faith, is composed of this rock; on which account the name sinaite has not inaptly been suggested for it. Like granite, it is often found porphyritic. If the hornblende, or its homologue, disappear, we have a rock called granitelle. The occurrence of mica in this, appears to be a superfluous, not necessary constituent.

Section 2. *Whitestone* (Weisstein).

This is characterized by compact feldspar, or albite, and the homologous species. The whitestone, properly speaking, is a mixture of compact feldspar and quartz. The fracture is splintery; the colors greyish, yellowish, and greenish-white. Compact feldspar, or albite, is indeed characteristic of the whitestone; but where this passes into granite, or approximates to it, it assumes a more or less sparry or granular texture. Mica occurs as an additional component, and may be recognised by its dark color, as also by the lamination which it produces. A variety in which grains of quartz and laminæ of mica can be distinguished, appears similar to several fine-grained modifications of granite, and has received the name of granulite. Crystals of feldspar, interspersed in the mass, give it a porphyritic appearance.

Eurite Porphyry. Under this head are to be found some of those red and black porphyries, termed quartzose. It is a porphyritic mixture of compact feldspar or adinole, with feldspar, albite, or an allied mineral. The colors are dirty flesh-color, running into green, and greyish white.

Claystone porphyry (porphyre terreux), a porphyritic mixture of a substance consisting of compact claystone, of an earthy fracture. It is not nearly so hard as eurite porphyry. The presence of silex imparts considerable firmness to it. Claystone porphyry is of a dirty flesh, violet, grey, and light color. Feldspar is separated either in distinct crystalline particles, or in indefinite angular fragments, in which latter case it forms a porphyroid.

Section 3. *Trachytes.*

This section includes rocks which contain vitreous feldspar (sunadin) as the principal constituent; the feldspar in most cases, even when recently laid bare, appearing as if it had been exposed to the weather. The rocks of this section are all of igneous origin.

Trachyte (trap porphyry, domite, feldspar lava). In this rock sunadin predominates, and as it often forms an aggregation of prismatic crystals, trachyte is very porous, and rough to the touch. The fresher the feldspar, and the greater its proportion, the more lustrous is the rock. A peculiar substance, termed andesin (most nearly allied to oligoclase), often replaces the feldspar, in that case forming the andesite of many geologists. Mica and basaltic hornblende are often contained in it, as also albite, which minerals modify the rock in various ways. Oxyde of iron frequently imparts a ferruginous tint, otherwise it is of a light color. A crystalline granular trachyte is distinguished from trachytic porphyry, porphyroidal trachyte, and scoriaceous trachyte.

The first of the above-mentioned rocks is a crystalline granular aggregation of feldspathic crystals, and in Italy, where it occurs very abundantly, is called saffomorto, or necrolite. Trachytic porphyry often contains feldspar in beautifully perfect crystals of different sizes. They lie in a matrix which appears more or less decomposed. Porphyroidal trachyte, instead of crystals of feldspar, contains only undefined angular fragments of feldspar. Scoriaceous trachyte derives its name from its appearance.

Clinkstone (phonolite, porphyry-slate). The petrographical constitution

of this rock is but little known. What we do know is, that it consists of an intimate combination of feldspar with an unknown body, which, in many cases, appears to be a zeolitic mineral; this union being sometimes so perfect as to give it the appearance of a simple mineral. Silex often communicates to it an extraordinary degree of hardness. A grey color is peculiar to it. It is often porphyritic, with crystalline glassy feldspar disseminated in its substance. The minerals generally included are mesotype, natrolite, chabazite, and apophyllite.

Section 4. *Obsidian.*

In rocks of this section the feldspar has been entirely fused, and only occasionally exhibits a crystalline structure. The action of fire is readily recognised, for which reason these rocks have more or less the appearance of glass.

Pitchstone. This is of imperfect conchoidal fracture, of waxy lustre, and of grey, green, red, brown, and black color.

Pearlstone is characterized by its granular or concentric lamination, and by its vitreous lustre, passing into iridescence. Its colors are grey, yellowish red, and brown.

Obsidian occurs, like all the rocks of this section, in volcanic regions. It is characterized by its striking conchoidal fracture and perfect glassy lustre. The broken fragments have very sharp edges, and strikingly resemble a dark colored glass. Its black and brown colors depend on carbonaceous substances, for which reason obsidian yields a white result before the blowpipe, by which it is distinguished from many slag-like rocks.

Pumice, or Bimstein. This is nearly allied to obsidian, and differs only in its condition of aggregation. While the former is perfectly glassy, this has a more or less perfect glass-like cellular spongiform texture. It is found in all stages of the spongy scoriaceous character, running finally into obsidian. Its economical applications are well known.

The rocks of this section frequently have their feldspar separated, and then occur as true porphyries.

Order 4. *Pyroxene Rocks.*

The rocks of this order are characterized by pyroxene minerals, particularly malacolite, augite, diallage, and hypersthene.

Section 1. *Pyroxenes.*

Only one species occurs under this head, *pyroxene rock* proper. This is a granular foliated mixture of malacolite with augite, and is of an oil or olive green color.

Section 2. *Leucitophyre.*

This section includes rocks consisting of leucite and augite. The mixture occurs in various degrees of perfection.

Leucitophyre (leucomelan). This exhibits a great number of modifications depending on its structure. The crystalline granular form (also called leucite lava) contains leucite and augite in crystalline grains plainly distin-

guishable with the naked eye. When the mixture is more intimate, the dark rock appears sprinkled with white. The porphyritic (dotted) lava is an indistinct mixture of uneven earthy fracture, in which lie crystals either of leucite or augite, or both. The compact leucitophyre is often very similar to basalt. The vesicular, slag-like, spongy, and glassy kinds, are sufficiently characterized by their names. The products of atmospheric decomposition proceeding from these rocks, are very favorable to vegetation; some varieties, as the slaggy, however, resist such influence most energetically. In places where this kind exists, as in volcanic or igneous regions, extensive tracts of land are barren and desolate. It is almost impossible even for cryptogamia to extract any inorganic nutriment from this durable rock.

Section 3. *Basalts.*

This includes several intimate combinations in which augite predominates, sometimes, however, replaced by basaltic hornblende. Magnetic oxyde of iron is usually associated with the augite, existing sometimes in a separate crystalline form. As the mixture of the constituents of basalt is so intimate, it is necessary to direct our attention to surfaces which have been acted upon by the weather. These plainly indicate the existence of labradorite, sometimes replaced by a zeolitic mineral. Olivine (common chrysolite) is an extra ingredient, but is so generally found in basalt, as to be considered an essential constituent by some geologists.

Basalt. This exhibits various diversities in respect to its state of aggregation, these being quite analogous to those which we have considered in rocks of undoubted igneous origin, as in leucitophyre; the names of the varieties, compact, earthy, vesicular, slaggy, spongy, and glassy, sufficiently indicate their distinguishing characters. This rock is of a very dark color.

Amygdaloidal Basalt. This is a variety of basalt in which occur spherical, ellipsoidal, and irregularly shaped cavities, generally filled or lined with crystallized or crystalline minerals, which are mostly zeolitic.

Section 4. *Dolerites.*

This section comes very near to that of the basalts. It embraces mixtures of augite with feldspathic and ferruginous minerals; among the latter magnetic oxyde of iron and specular iron are in a more or less crystalline condition.

Dolerite (basaltic greenstone). Augite, generally the predominant component, exerts the greatest influence on the character of dolerite. Its dark color depends on augite, being varied to lighter by feldspathic substances (especially labradorite). Some one or other ferruginous mineral appears always to be present. This exerts a great influence on the color of the rock; in the ochrey condition it penetrates the mass, and colors it reddish-brown. The components of dolerite are generally distinguishable; there is, however, a modification, exhibiting a less degree of crystallization, and forming an insensible transition into basalt; this is known as anamesite. Dolerite is exhibited as crystalline, granular, porphyritic, vesicular, or slaggy (as in dolerite lava).

Section 5. *Trap Rocks.*

The term trap was formerly made to embrace many species essentially

different. It is therefore a matter of some doubt to which the name shall be applied in restricting the appellation. The name is derived from a species of rock which forms a cap on the Scandinavian Trapp-berg, elevated in a terraced or step-like manner. This rock is now assumed as the typical trap. It is a mixture of augite and some feldspathic mineral, generally labradorite, or its compact variety, saussurite.

Trap Proper. This rock varies in respect to the distinctness of its ingredients, and is of a very dark color, owing to the augite. When oxyde of iron pervades the mass it imparts a brownish shade. It occurs porphyritic, granular, and compact. Trap porphyry, which contains crystalline labradorite or feldspar in the trap mass, is sometimes called melaphyre.

Amygdaloidal Trap is a compact trap, with cavities containing various minerals. The principal of these are either silicious, as amethyst, chalcedony, opal, &c., or zeolitic, as mesotype, stilbite, desmine, apophyllite, harmatome, &c.; likewise, calcareous spar, spathic iron, and brown iron ore. The occurrence of manganese ore is of especial economical importance.

Section 6. Diabase.

The mineral predominating in these rocks is hypersthene, which occurs in combination with some feldspathic material, as labradorite, albite, and with chlorite. The amount of labradorite is not inconsiderable, yet it has not as much influence on the color as the chlorite. This color is green with the latter mineral. Diabase mixtures exhibit a tendency to intimate combination, on which account the crystalline structure disappears more or less, and this in proportion to the extent to which the earthy chlorite is distributed in the rock.

Diabase Proper (greenstone), which is of a granular porphyritic and compact character, is very hard and difficult to break; the color is dark in proportion as it contains hypersthene, or augite, and chlorite.

Greenstone Porphyry is an intimate diabase combination from which sparry or compact feldspar, labradorite, saussurite, or oligoclase, is separated.

Variolite. A diabase of a dark color, with roundish light particles included.

Amygdaloidal Diabase. This is a fine grained diabase in which lie amygdaloidal, or undefined masses of brown spar, or calc spar. Variolite (Blatterstein) is, on the whole, a compact rock of an earthy fracture. Its colors vary between green, grey, brown, and black; the first of these predominates. Genetically considered the rock seems to have acquired the amygdaloidal character by the influence of vapor, ascending gaseous bubbles leaving cavities which were subsequently filled by infiltration. The slaty diabase amygdaloid or tabular spar, distinguished from the preceding by its laminated texture, presents other marks contributing essentially to its specific character. In its green or brown mass there lie spheroids which are frequently flattened. In this case the flattened sides lie parallel to the planes of stratification. Chlorite may occur separated like calc or brown spar. The calc spar passes into compact limestone, which then forms beds

alternating with the tabular spar. Oxyde of iron sometimes penetrates the rock in considerable quantity, forming a poor ironstone. The presence of much talc gives it a soapy feel.

Section 7. *Hypersthene.*

Under this head, which includes rocks in which hypersthene is mixed with feldspar, or some allied mineral, are especially distinguished:

Hypersthene rock. This is a crystalline granular aggregation of labradorite or saussurite with hypersthene. The latter exerts the greatest influence on the rock, often occurring in so great quantity that the feldspathic mineral is entirely removed. Hypersthene rock is therefore of a dark color, and resists in a remarkable degree the action of the weather. The addition of chlorite converts it into diabase, and when diallage enters into combination it becomes euphotide.

Section 8. *The Euphotides.*

In these rocks diallage is combined with labradorite or saussurite.

Euphotide (gabbro, granitone). This is a crystalline granular combination of the above-mentioned minerals. Diallage is generally the prevailing constituent of this exceedingly hard rock. The color is that of diallage, an undefined grey passing into brown. Hypersthene and some other minerals are often added. It passes into hypersthene rock, more rarely into the rocks of the following order; it resists, almost entirely, the decomposing action of the atmosphere.

Order 5. *Rocks of Schiller Spar.*

Schiller spar or metalloidal diallage, which is a well known mineral, is also entitled to a place among rocks. It is either pure, or mixed with saussurite. Should the latter be the case, it is often variolitic, the saussurite being separated in round particles surrounded by schiller spar. In porphyritic schiller rock, distinct crystalline foliated masses of schiller spar occur. Common schiller rock (primitive greenstone) often alternates with serpentine, and in fact bears a considerable resemblance to it. It is either pure compact schiller spar, or else mixed with a little saussurite.

Order 6. *Serpentine Rocks.*

The rocks of this order contain serpentine as their characteristic constituent.

Serpentine Rock. Serpentine, like schiller spar, ranks both as a mineral species and as a rock. It is principally common serpentine that occurs in the latter condition, the precious and fibrous being restricted to small portions of its mass. Green is its peculiar color; the different shades, other than this, depend on the presence of foreign substances. It is exceedingly rich in foreign species, among which asbestos, pyrope, magnetic oxyde of iron, &c., are the most conspicuous.

Ophite. This rock, so much used, especially for purposes of art, is a

mixture of serpentine and compact limestone. The limestone is often separated as marble, and veins colored by different substances give it a very beautiful appearance; verd antique marble is here included.

Order 7. *Amphibolic Rocks.*

Minerals of amphibolic character, as grammatite, actinolite, asbestos, anthophyllite, hornblende, &c., form the predominant ingredients in rocks of this order. It is hornblende, however, either pure or in combination with other bodies, which forms the mass of the rock.

Hornblende rock is nothing more than hornblende in a pure state, or with a few unimportant additions. Two kinds of this rock are distinguished: hornblende-rock proper, and hornblende-slate. The former is crystalline granular, and less hard than tough. It is therefore difficult to break or blast, and forms a considerable impediment in the way of mining or excavating. Hornblende-slate, which consists of scaly hornblende, possesses a rather imperfect stratification, with the same greenish-black color as the last. Actinolite and anthophyllite occur in both varieties, as unessential ingredients. Other minerals also occur, and cause the transition and hornblende flagging-stone, hornblende gneiss, syenite, diorite, &c.

Diorite (greenstone). This rock was formerly considered to stand in such a relation to diabase, as to be entitled to consideration only as a variety of the latter. The more careful investigations of Hausmann have, however, shown that they are essentially different. While the former contains a pyroxene mineral, hypersthene, as the predominating constituent, in combination with a feldspathic, as labradorite, or albite, and chlorite, the latter (diorite) is a more or less distinct mixture of an amphiboloid substance, hornblende, with albite. It is, in composition, nearly allied to syenite. The hornblende imparts to it a dark greenish-black color. The difference in the manner in which the combination of the constituents takes place, permits a distinction into: granular diorite, whose particles are crystalline granular; globular diorite, in which its granules are enveloped by concentric coats of compact feldspar, or a variety of hornblende; porphyritic diorite, where albite is interspersed in the mass; and compact diorite (aphanite) consisting of a very intimate mixture of the above-mentioned minerals. Both the diorite and hornblende rocks are capable of withstanding the action of the atmosphere to a very high degree. The feldspathic matter weathers first, and gives rise to a very rough surface, well calculated for the abode of various cryptogamous plants. Umbilicaricæ, for instance, occur in such localities in great perfection and profusion.

Order 8. *Calcareous Rocks* (*Limestones*).

The carbonate of lime of mineralogy, either pure or combined with other substances, is an exceedingly important constituent of the earth's crust.

There is, perhaps, no other to be compared with it in this respect. It not only forms immense masses in particular localities, but is universally distributed, this being the case both with respect to the pure varieties and to the mixed.

Section 1. *Limestone Proper.*

This section includes all rocks composed of pure carbonate of lime. The principal modifications are :

Marble, or pure carbonate of lime in a crystalline granular state of aggregation. The name of marble is often applied, vulgarly, to rocks which are not entitled to it. It is not upon the markings of a limestone, whether close-grained or crystalline, that the title of marble, geologically speaking, is based, but simply upon the condition of aggregation. A marble may, and indeed often does, have various kinds of coloration or other markings, but then it is not every limestone thus marked that is a marble. The markings often depend upon the penetration of the limestone by other matters. Common marble is pretty generally distributed in various degrees of fineness and purity. The hardness varies considerably, one extreme being as conspicuous as the other. The use of marble in building and sculpture is well known. The white variety, as it occurs near Carrara, in the Appenines, in the island of Paros, and in Mount Pentelicus in Attica, is the most esteemed. This is not so frequent as the yellow, greenish, grey, and bluish modifications. It sometimes appears black, and then passes into anthraconite. The presence of various colors imparts a spotted, pitted, or veined appearance. Marble contains various incidental ingredients which sometimes cause it to deteriorate in value. Iron pyrites is sometimes so intimately combined as to escape detection. Under the influence of the atmosphere a hydrated oxyde of iron is formed, which imparts a brown color to the surface. Hence it is that many columns or structures of marble become coated with a yellowish tinge. Augite, schorl, feldspar, hornblende, mica, &c., are also frequently met with, and have given rise to the separation of various rock species, which, on account of their limited occurrence, are not generally recognised. This is the case, for instance, with the feldspathic, pyroxenic, pyropian, amphibolic, and cipolin calciphyre of A. Brogniart.

Breccia Marble is a combination of angular fragments of marble by a calcareous cement. The two portions are generally of a different color.

A weathering of marble is out of the question, as the atmosphere is incapable of causing the decomposition of carbonate of lime. A crumbling away of the rock may, however, be effected by the decomposition of the interspersed sulphuret of iron, and of the carbonates of metals, causing a necessary swelling of particular portions at the expense of others.

Compact Limestone. This form of calcareous matter is the most important, in a geognostical point of view, and embraces a large number of varieties.

The common compact limestone possesses, on a large scale, a conchoidal, on a small, a splintery fracture. It is mixed more or less with other substances, especially with particles of clay, which cause a diminution of

hardness, and silicious particles, which cause an increase of hardness. The degrees of hardness are very different, as also the colors, which vary from white, through grey, bluish, and reddish, into black. Different colors sometimes co-exist, similar to what is seen in marble, and produced by like causes. Carbonates of iron and manganese are not uncommon constituents, which impart to the stone, when long exposed to the weather, a ferruginous or brown crust.

Limestone shale is distinguished by its fine lamination, rather thick than thin, however, and by its extraordinarily fine grain. It is important for its use in lithography. Its principal locality is at Solnhofen, not far from Pappenheim.

The other varieties, the breccious limestone, the columnar, mamillary, the cavernous, and the cellular limestones, are sufficiently well characterized by the names. The cellular is of a marly character, traversed in various directions by a purer mass, which is often calcareous spar, thus producing the cellular character. Oolite, or roestone, is an aggregation of globules of compact limestone, from the size of a pea (when it is sometimes called pisolite) down to very minute particles, the individual particles often cohering with extraordinary firmness.

Calcareous Tufa (travertine). This more or less porous rock, on account of its lightness and facility of working, affords an excellent building material. The pores depend partly on organic matters, which it incloses, and partly they are interstices left throughout the aggregating material. It is frequently colored yellow or brown by oxyde of iron or manganese; white, however, generally predominates.

Scaly Limestone, or limestone with a scaly lamination, is produced by hot calcareous springs. It occurs at Carlsbad, and other places.

Chalk is carbonate of lime in an earthy condition.

Tripoli (rotten stone). Combination of silex and alumina with lime. Light, earthy, stains paper yellowish or greyish-white.

Marl consists of clay with limestone, and has an earthy, somewhat plane fracture. Colors greyish.

Section 2. *Silicious Limestones.*

This comprehends limestones with a greater or less proportion of silex.

Porous Limestone occurs in nature as compact and granular. It is rough to the touch, and has the peculiarity of soaking in water greedily, without giving afterwards any indication of its presence.

Silicious Limestone (conite) possesses a variable proportion of silex, and is without the property exhibited by the preceding species with respect to water.

Chalk Rock. Limestone with a good deal of silex, a little clay, and some carbonate of iron. It is important in a technical sense, owing to its property of hardening under water, and hence well adapted for submerged walls.

Section 3. *Marls.*

These are rocks composed of carbonate of lime with clay, probably not

in chemical combination. Lime predominates. Marl forms masses which are either slaty or indefinitely shelly. The lamination of the rock is very decided, causing it to fall to pieces readily.

Lime Marl. Nature has drawn no lines between the different kinds of marl. The species can be determined only approximately by the prevailing component. An artificial limit has been set between them. According to this, lime marl, of which there are the varieties, marly limestone, marly lime slate, and marly earth, must contain over seventy-five per cent. of carbonate of lime. When it contains between seventy-five and fifty per cent., it is called *clay marl.* This occurs in not inconsiderable masses; and in an agricultural point of view is as important as the marls in general. The color and hardness vary considerably, the former being greyish, yellowish, reddish, greenish, and white. The grey and black colors are due to bituminous particles, the green to chlorite. Clay marl is not decomposed, but crumbles to pieces readily; water penetrating between the laminæ and into the pores by capillarity, experiences an expansion by heat or freezing, which splits the rock into fragments.

Fetid Marl. Marl often contains so much bitumen as not only to be colored brown or black, but to emit a strong odor when struck. The outer coating is frequently white, the effect of evaporation or abstraction of the bituminous particles. Fetid marl rock is distinguished from fetid marl slate and fetid marl earth. The three varieties are only defined by their external appearance. The fetid marl slate, also called bituminous marl slate, is in many places entirely impregnated with copper ores; on which account it is in many places mined and worked for copper, notwithstanding that it generally contains only three per cent. of the metal. The bitumen which penetrates the rock is often separated in a pure state, and singularly enough, principally in places where there are organic remains; so that the supposition that the bitumen depends upon such remains, and is nothing else than a product of decomposition of organic matter, seems to be not entirely without foundation.

Section 4. *Fetid Limestone*

Embraces those limestones that are so transformed by coaly or bituminous substances, as to possess a dark color, and to diffuse a bituminous odor when struck.

Fetid Lime, or bituminous limestone. It is divided into fetid lime, fetid clay, oolitic fetid lime, breccious, and porous or cellular. The more bitumen the rock contains, the darker are its colors, which are generally grey, brown, or brownish-black. Those portions exposed to the air are generally lighter, often entirely white, the inside remaining dark. This is caused by the passing off of the bitumen leaving the rock somewhat porous. The bitumen is often separated as asphaltum. The rock is often penetrated by other foreign matters. Thus there is frequently a fetid quartz corresponding with the rock crystal in pure limestone.

Anthraconite, or carbonate of lime with a considerable amount of carbonaceous matter. This occurs compact and scaly granular. Threads of white limestone, or brownspar, often run through it.

Order 9. *Magnesian Limestones.*

The rocks constituting this order consist of magnesian matter, or of a combination of carbonate of lime with carbonate of magnesia.

Magnesian limestone is the purer combination of the two above-mentioned substances, and is divided into dolomite and compact magnesian limestone. Dolomite bears the same relation to the other rocks of this order, that marble does to the limestones: the crystalline granular structure is characteristic of it. Its colors are exceedingly varied, as also its degree of hardness. White predominates; the tint may, however, be blue, grey, yellow, or ferruginous (from oxyde of iron). It abounds in foreign ingredients, on which account it is not unimportant to the mineralogist. The compact variety possesses a brittle, flat, conchoidal fracture, and is generally harder than compact limestone.

Fetid Magnesian Limestone contains a portion of bitumen, which imparts a dark color, frequently modified by oxyde of iron. The crystalline granular, which is either scaly or an aggregation of magnesian rhombohedrons, has a rough appearance, and an iridescent lustre on the crystalline particles. Other varieties are the compact, breccious, cellular, porous, and earthy.

Magnesian Marl. This is a very impure magnesia, containing, in addition to the usual magnesian combinations, carbonate of iron or manganese, alumina, and silex. The fracture is earthy and uneven. When fresh it is of a grey or bluish color. When exposed to the weather, the carbonates of iron and magnesia suffer decomposition, and hydrated oxydes of these metals are produced, the former penetrating the white rock, and coloring it rust or liver-brown, while the latter is separated in a dendritic form.

Ferruginous Brown Lime. A mixture of magnesian matter with carbonates of iron and manganese. When fresh, it is yellowish or reddish-white; when weathered, ferruginous. Three varieties are distinguished: scaly, granular, and compact.

Order 10. *Gypsum Rocks.*

The rocks belonging under this head, of far less geognostical importance than the lime rocks, consist of sulphate of lime. There are two species which represent this order:

Gypsum (*pl.* 36, *fig.* 12), or the hydrous sulphate of lime, occurring as spathic, scaly, granular, compact, and breccious. The compact is most abundant; the other varieties are found in it in greater or less abundance. The characteristic color is white. Bitumen, which frequently penetrates the rock, produces a dark color, and at times beautiful markings. In less quantities it colors the gypsum blue. A very pure and compact variety of gypsum is known as alabaster. Spathic gypsum not unfrequently occurs in

distinct crystallizations on the compact variety in a porphyritic manner. It contains various mineral substances not essential to its composition. The second variety is:

Anhydrite, or anhydrous sulphate of lime. Of its mineralogical modifications only the scaly-granular, radiated, and compact, are of geognostical importance. White prevails less, as a color, than grey and blue. Anhydrite becomes converted into gypsum by attracting moisture from the atmosphere. During this chemical action a considerable increase in volume takes place, by which whole masses are crumbled to pieces or shattered.

B. Heteronomic Rocks.

It has already been mentioned that by heteronomic rocks we understand those in which two principal parts are to be distinguished. The one consists of hard pieces, or fragments, the other of a generally earthy, or compact mass, which cements these pieces, as it were, into a whole. To assist in furnishing a clearer view of the subject, let us illustrate the manner in which some of such species of rock may arise. In attentively examining the action of currents of water on masses of rock, we find that fragments of these are, by various agencies, broken off or loosened, and carried away. In the transportation the sharp corners and edges are worn down by the attrition produced between the different pieces, until finally the mass is reduced to an ellipsoidal or globular form. In this way may be produced boulders, pebbles, and sand. The size may vary from that of coarse sand to blocks or masses of considerable magnitude, depending upon the original size of the fragment, the hardness of the material, and the length of time during which the rolling has continued, as also upon the velocity of the current. Stones may in this way be brought from the heads of streams, and carried out into gulfs of the sea, there to be distributed in layers. The fine sand or comminuted matter suspended in the water, whether resulting from this attrition or from other causes, will be deposited when the current is weakened by its expansion into the aforesaid gulf or bay, and will occupy the interstices of these rounded stones. By the upheaving of the bottom, exposure to the atmosphere, or igneous action, the mass is indurated in the course of time, and thus a truly heteronomic rock is exhibited. This method of formation does not apply to all heteronomic rocks, many of them being produced by the destruction of isonomic rocks in other ways. An essential difference in character enables us to distinguish heteronomic rocks into conglutinates and congregates.

a. Conglutinates.

In conglutinates the connexion of the particles or parts is effected by a combining medium of different character. This difference in character may be only in the state of aggregation, since the parts may be cemented

by a mass of similar chemical character or composition. Where this is the case it is often difficult to decide whether the rock belongs to the isonomic or to the heteronomic, the passage from the one class to the other being effected by such forms.

Series 1. *Sandstones.*

Sandstones are conglutinates of fine grains, generally uniform in size. The part combined consists of quartz granules, which are either indefinitely angular or round. The cement is either a simple mineral or a mixture of various bodies. The principal kinds are :

Quartz Sandstone, in which quartz grains are connected by a quartzose cement. The color is generally light ; grey, brownish, yellowish ; seldom pure white. Its hardness is considerable.

Chalcedony Sandstone. This is of considerable hardness, as would naturally follow from its composition, consisting of quartz grains combined by chalcedony. Color grey, yellow, or blue.

Argillaceous Sandstone. This is extensively distributed, and of great importance as a building material. The cement is argillaceous, and accordingly the rock, when breathed upon, emits the characteristic odor of this substance. Its color may be either light or dark, these being sometimes so combined as to produce markings. Its hardness is less than that of the preceding varieties. The clay is occasionally separate, in masses of a spheroidal shape, as in the well-known clay stones. Mica not rarely occurs as an ingredient, and then contributes to the lamination.

Calcareous Sandstone. The cement here consists of carbonate of lime. Its colors are frequently similar to those of the preceding ; it may, however, always be distinguished by the effervescence produced by acids. The cement is rarely crystalline.

Marl Sandstone. The cement is sometimes clay, sometimes lime marl. It therefore effervesces upon the application of acids, and emits an argillaceous odor when breathed upon. Colors white, green, grey, and red, these often darkened by carbonaceous particles.

Iron-clay Sandstone. The cement is an iron-clay, frequently separated in clay stones. Its principal color is reddish-brown, in which white and grey not unfrequently produce markings. It is sometimes so thinly laminated that large plates may be obtained.

Iron Sandstone. The cement is limonite or argillaceous oxyde of iron. The grain sometimes increases so much in size as to give rise to a true iron conglomerate. Colors generally dark-brown and yellow.

Series 2. *Conglomerates.*

The conglomerates are combinations of fragments of simple minerals or compound rocks, angular or rounded ; the cement either a simple mineral or itself a conglomerate.

Iron Conglomerate. Fragments of quartz, clay slate, and, at times, of other rocks, are combined by hydrated oxyde of iron. The cement is sometimes yellow, sometimes brown iron-stone, the pieces combined being at times so sparingly distributed, that the rock passes into limonite ; on the other hand, the fragments may be in such large proportion as completely to

throw the cement into the background. The parts combined are often so minute as to permit the passage into iron sandstone. It is generally found in peculiar forms, particularly of tubular and stalactitic shapes. A remarkable variety is exhibited in the iron-stone conglomerate which is found in Brazil, and there termed tapanhoacanga (negro-head). It consists of pieces of specular iron, micaceous iron, and magnetic oxyde, cemented by red or brown iron-stone. Among the foreign admixtures of this rock are gold and the diamond. It is from this rock that the diamonds of Brazil and the East Indies are generally obtained.

Granite Conglomerate (regenerated granite, arcose). Crumbled, weathered granite, the feldspar of which has been entirely decomposed, is often combined in such a manner by argillaceous oxyde of iron, or hydrated oxyde, as to present an appearance not unlike real granite. The hardness of this conglomerate is less than that of granite, sometimes being exceedingly loose in its texture.

Porphyry Conglomerate. Angular or rounded pieces of more or less decomposed eurite or clay porphyry, are connected by an earthy mass, which itself appears to have proceeded from the decomposition of porphyry. The cement sometimes so completely permeates the cemented, as to render a separation impossible. With the porphyry are frequently fragments of clay and silicious slate, granite, gneiss, mica slate, &c. The general color is brown, often with light spots, resulting from decomposed feldspar. A solid cellular variety, permeated by silex, affords an excellent material for millstones.

Trap Conglomerate. Fragments of trap rocks, principally porphyritic trap and porphyroidal trap, are cemented by a mass which appears to have been produced by the attrition of the trap. This cement is often so similar to iron-clay as to be difficult of distinction. Pieces of eurite and clay porphyry, as also of granite, clay, and mica slate, are often intermingled in the conglomerate. The predominant color is reddish-brown with a violet tinge.

Iron-clay Conglomerate. Fragments, partly angular, partly rounded, of the most different simple or compound rocks, are combined by an iron-clay of an earthy weak fracture. The cemented parts are principally pieces of quartz, feldspar, clay and silicious slate, granite, gneiss, flagstone, and various porphyries. Their size varies from the largest lumps to the grain of the finest sandstone.

Grauwacke. This is a conglomerate which undergoes the widest modifications. Lumps and fragments of the most various kinds are combined by a clay slate cement. There generally occur in it quartz, silicious slate, clay slate, feldspar, mica, granite, various porphyries, and other compound rocks. Quartz seems, however, to predominate. The fragments sometimes occur in such proportion as completely to hide the cement. Grauwacke varies greatly with respect to the grain: while, on the one hand, the rock is composed of no inconsiderable pebbles or rolled fragments, on the other, these are so imbedded in the cement as to lie entirely concealed. The cement even appears at times to be coarser than the parts cemented. A grey color predominates.

The three varieties which have been distinguished possess an essentially different character as regards their structure. Common grauwacke is the modification exhibiting the components most clearly. To this belong the coarse, small, and fine-grained grauwacke, all of considerable solidity. The slaty is a finely granular variety, generally of a thick lamination. On the surface of lamination, clay-slate and mica not unfrequently occur conformable to the lamination. We must not confound this with grauwacke slate, which appears exceedingly like clay slate, and sometimes passes into it. The mixture is very thorough, and the lamination less evident than that of clay slate. Besides the difference in fracture, the two rocks may be distinguished by their mode of cleavage. While clay slate may be separated into acutely-angled parallelopipedal pieces, the cleavage of grauwacke slate is into ellipso-spheroidal concentric shells.

Silicious Conglomerate. Rounded or angular pieces of silicious mineral are cemented by a silicious medium. Its hardness and solidity are considerable; the predominant colors grey and white. The grain is very various. It may be so fine as to pass into sandstone. Pudding-stone is a silicious conglomerate in which rounded fragments of flint are cemented by silicious matter.

Nagel-fluh (calcareous breccia). This peculiar name comes from the Swiss, and means nail rock. The appellation has been derived from a peculiar appearance presented by the weathered rock, in that the pieces of cemented matter protrude from the surface, like so many heads of nails or spikes. The portions cemented are united by a medium of similar character, only of a finer grain. This rock is distinguished into silicious, calcareous, and common breccia (nagel-fluh), as either of these ingredients is in excess, or neither predominates. The size of the particles varies considerably, as does that of the grains of the cement.

Calcareous Conglomerate. Blocks or fragments of various rocks, as lime, clay, silicious slate, &c., are united by a calcareous cement, often penetrated by oxyde of iron. Pieces of lime predominate. The compact or earthy cement is sometimes crystalline.

Shell Conglomerate. A combination of shells, generally broken, or corals mixed with quartz or other silicious minerals, united by oxyde of iron, limestone, or calcareous sinter. The rock is sometimes soft, sometimes hard and compact; in the latter case it affords an excellent building material.

Trachytic Conglomerate. Fragments, generally angular, of trachyte or its allied rocks, as pearl, pitch, pumice-stone, and obsidian, are connected by a cement resulting from the chemical decomposition and mechanical attrition of these same substances. The fragments vary from a diameter of several feet to the size of a nut, the latter being most prevalent. This rock, on the whole, possesses little solidity; it often contains opal in its various modifications. The varieties are:

Trachytic Breccia, or trachytic conglomerate, with the contained fragments, generally angular, and predominating.

Trachytic Tufa. The opposite here prevails, the cement predominating. Here belong some rocks which are distinguished by their color and

structure, but are only modifications of trachytic tufa. Thus we have peperino, which presents an ash-grey cement, whose uniformity is interrupted by slaggy particles and glassy feldspar; also the pausilippo-tufa, of a yellow color, and frequently possessing a certain porosity; together with the Rhenish tufa, tras or terras, in which pieces of pumice are joined together by a grey earthy mass.

Basalt Conglomerate (trap tufa, Tuff-wacke). This rock is a conglutinate of basaltic fragments and of various other rocks, which are combined by an attrition-product of the basalt. Vesicular basalt is of most general occurrence, as also clinkstone trachyte, granite, sandstone, mica slate, and quartz. Augite, basaltic-hornblende, olivine, wood-opal, brown coal, and some other mineral substances, are often distributed throughout the earthy mass. The hardness is inconsiderable.

Leucitophyre Conglomerate. The character of this rock is much like that of the preceding. Fragments of leucitophyre, or of similar rocks, are combined by pulverized leucitophyre substances. Leucite frequently occurs in perfect crystals, as also mica and augite; more rarely melanite and hauyne.

Pumice Conglomerate. This is composed of pumiceous matter cemented by a clayey substance. It is generally very light and porous, but, with some degree of hardness, furnishes a good building stone.

b. Congregates.

These are combinations of different particles which possess so little coherence as to form soft, light, or loose aggregates. Congregates are heteronomic masses in which the cement is wanting.

Series 1. *Clays.*

The clay of the mineralogist occurs also in masses entitling it to the attention of the geologist. It is a silicate of alumina, with a varying proportion of water, contaminated by a number of different substances whenever it occurs in large quantity. Among these substances are especially to be found lime, coaly and bituminous particles, oxyde of iron and sand, which may be separated by washing. A preponderance of any particular ingredient determines its character, as:

Iron Clay, which contains a considerable proportion of oxyde of iron, and is therefore of a reddish-brown color.

Marl Clay, containing a large amount of carbonate of lime, and exhibiting various modifications, as the ferruginous, common, sandy, and bituminous.

Drawing-Slate. This is a clay slate penetrated by a considerable quantity of carbonaceous matter. It produces a streak, and is brought into trade under the name of black chalk. It is of a pure black color.

Bituminous Shale, or burning shale. This is a clay shale, impregnated by bituminous matter. It is distinguished from drawing-slate by its power of burning with a flame. The color is rather brown than black.

Clay Shale, an earthy clay of more or less slaty structure, and of a grey color, running into black by the addition of carbonaceous matter. It has a powerful attraction for water; so much so, that when the tongue is touched by a small piece the two adhere firmly.

Clay. Of an earthy consistence, and readily rendered plastic by water. It contains sand more or less easily removable by washing. Several kinds are distinguished:

Porcelain Clay. Of a white color, which is permanent in baking. It is closely allied to kaolin, or clay resulting from the decomposition of feldspar.

Pipe Clay. Of a grey color, produced by a slight admixture of bituminous matter. This clay becomes white by burning, and is well adapted to the manufacture of tobacco pipes and common ware.

Potters' Clay. Of various colors, grey, yellow, and reddish-brown.

Loam. This occupies a place intermediate between clay and sand; it is of an earthy and sandy feel. The sand, distributed in great quantity, although not always visible, may readily be felt. Colors grey, brownish, and reddish. When it contains much lime it becomes marl loam.

Series 2. *Soils.*

This series embraces thorough and loose mixtures of various substances. The conditions of aggregation, as well as the colors, are exceedingly diversified, these being modified principally by a greater or less proportion of humose substance, and by iron, and perhaps manganese combinations. The different soils vary much in their capacity of taking up water. The weathering of various rocks, as well as their mechanical separation or division, is the principal source from which they are derived; for this reason their composition is of great diversity. Lime, magnesia, potassa, soda, and oxydes of iron and manganese, are of most general occurrence as bases, these being combined with carbonic, silicic, sulphuric, phosphoric, and nitric acids, as also with chloric and fluoric. The organic matters consist of vegetable mould under various forms, as humus, geine, ulmine, humic and ulmic acids. Salts of ammonia also occur. Particular kinds are determined by the predominance of individual ingredients; the full investigation of these soils and their properties belongs not to this subject but to agriculture. The principal of these soils are:

Clayey Earth. An earthy mass with clay in excess. It absorbs a large quantity of water, thereby becoming plastic; on drying again it becomes very hard, and exhibits extensive cracks and fissures, owing to the shrinking in volume. The consistence of the soil is generally solid. Grey, yellow, brownish, and bluish, are the most conspicuous colors.

Loamy Soil. This occupies a position intermediate between a clayey and a sandy soil, just as loam does between clay and sand. The earthy mass is generally of a brownish or yellowish-grey color, furnishing a fruitful land when calcareous particles enter also into combination.

Sandy Soil. This contains an excess of quartzose sand, in an earthy, clayey, or marly mass. It is very loose, and of a grey, yellowish, or whitish color, takes up little water, parts with it readily, and quickly becomes dry.

Calcareous Soil. An excess of calcareous particles in loose mixture with clayey and sandy matters. It is of a light color, often changed by humose substances. It absorbs water, yet without becoming plastic, and readily parts with it again. It overlies chalk, calcareous tufa, and other limestone rocks.

Iron-clay Soil. This is of a reddish-brown color, and arises from disintegrated iron-clay or decomposed ferruginous rocks. It readily takes up water, and holds it very tenaciously. On the escape of the water the earth shrinks and becomes fissured.

Iron Soil. This is of very complex composition, and appears to be principally a product of decomposition of pyroxene and amphibolic rocks. The considerable proportion of oxyde of iron imparts to it a yellowish or brown color. It absorbs much water, retains it firmly, and parts with it again without fissuring.

Humose Soils. The humus which characterizes this soil rarely amounts to over one fourth of the entire mass. Sand, clay, and more rarely lime, are associates in it. When dry it is very apt to be dusty, and when wet of a boggy or miry character; its color is brown or brownish-black. It readily combines with water, and contracts slightly on drying. Many kinds of humose soil are known in agriculture. Among these the heath soils are conspicuous: soils with remarkable hard particles, resulting from the decomposition of species of erica or heath.

It frequently happens that fragments and blocks of various rocks are distributed in soils, of various shapes and sizes, and in such excess as almost to displace the soil itself. The manner and origin of their accumulation, as well as the petrographical peculiarity of these fragments, are entirely dependent on the position of the bed of the earth. The most conspicuous ingredients occurring here and there in soils are gold, arsenical pyrites, and iron pyrites. The ground is frequently impregnated with various salts, which, under favorable circumstances, effloresce so as to form a white incrustation. The principal of these salts are common salt, glauber salts, epsom salts, potash and soda, saltpetre, &c.

Series 3. *Sands.*

These embrace masses presenting themselves as accumulations of fine angular or rounded grains. They are generally quartzose, although other substances than quartz may constitute sand. The principal species are:

Quartz Sand, or a loose accumulation of quartzose particles. There are various modifications, characterized by a greater or less degree of purity. Yellow sand derives its color from hydrated oxyde of iron, this being so firmly combined as to require the action of acids to eradicate it. The principal varieties of sand are characterized by the presence of lime, dolomite, augite, garnet, iron, mica, gold, platinum, shells, &c. Jewel sand contains many of the precious stones, as diamond, spinelle, zircon, garnet, &c.

Series 4. *The Gravels.*

Here belong those very loose aggregates which plainly exhibit traces of a

long-continued disturbance of various rocks. One of these may furnish the whole supply, or several may be combined. They are known as granitic, porphyritic, syenitic, marly, tufaceous, calcareous, basaltic, pumiceous, &c., gravels.

Series 5. *Pebble Beds.*

These are distinguished from the last by the rounded character of the ingredients, and by their generally smaller size; the principal kinds are the calcareous, silicious, and gem beds. Fragments of sapphire, topaz, chrysoberyl, as also pieces of gold and rare ores, are often found associated.

III. GENERAL OREOGRAPHY.

The rocks, whose consideration, according to the system of Hausmann, we have just completed, are those which, in greater or less accumulation, compose the crust of the earth. Great diversities, however, are exhibited in the manner of their occurrence, as well as in the relations they bear to each other. The surface of the earth appears to present to us the greatest diversity of structure, in the most varied, and apparently irregular inequalities of elevation and depression: precipitous declivities, washed by rushing waters, rise up in fruitful valleys, and mountain ranges bound the horizon in the blue distance. Here are displayed smiling fields, or meadows embraced by noble forests cover the extended plains; there is seen a sandy waste, seemingly capable of supporting only the sparsest vegetation, while, in another place, jagged rocks stand out from cloud-capped heights, shutting out the beams of the setting sun. Seas, with foaming waves, wash away the coasts, and reveal the buried secrets of the earth. These irregularities and inequalities are, however, by no means accidental; they proclaim great causes, which have thus modified the surface of the earth. Since stones or rocks compose the crust of the earth, and cause these irregularities, a new field opens to us in the investigation of rock formations (*oreography*). This department of our subject treats of rocks as they occur in great masses. Investigations of this kind have led to the most astonishing and stupendous results, in revealing to us the certain or probable action of mighty causes, in producing the effects we see around us. The solid crust of the earth is well calculated to exhibit the traces of expended forces; not so with the atmosphere and the terrestrial waters. The hurricane may rage, and the waves be one moment heaped up mountain high, and the next sink down again into the abyss; lightnings may play and thunder roll; yet the waters when calm and the sky when clear, exhibit not a vestige of the commotions which agitated them. Not so with regard to the coast, whose incumbent rocks have been shattered by the surge, or the forest, whose vegetation has been mowed down by the blast; they (and the solid portion of the earth's crust) alone present durable evidence of such mighty agencies. If, again, we examine the phenomena caused by volcanoes, where torrents of lava have annihilated blooming fields, where subterranean explosions

have shattered mountains, where showers of ashes have buried cities, and earthquakes have paralysed whole nations with terror, there it is that nature cannot so readily erase the traces of such catastrophes. In such ways changes of original condition may occur, leaving a very definite character. These changes are to us the hieroglyphics which describe the past history of our planet, and the unriddling of which is the business of the geologist. He indicates the causes, the geognosist only the effects. Causes, however, are known by their effects, and for this reason the study of the latter must precede that of the former. As in the investigation of any object the exterior must first be subjected to examination, before the internal peculiarities can be studied, so we but act according to sound reason in going first into the consideration of the exterior of mountain masses, and then into that of their interior, the structure, and the constituents. This spheroid on which we live, and whose polar flattening amounts to $\frac{1}{300}$, possesses an average density of 5.67; or in other words, its density is 5.67 times that of pure water. The mean density of the earth's crust is, however, but 3.0; it must consequently increase towards the centre, and become greater than 5.67. If we assume that part of the earth whose density is 3.0, to extend to a depth of one fourth its radius, then the density of the interior must exceed that of wrought iron, or be more than 7.7.

It has been calculated that nearly three fourths of the surface of our planet are embraced by the sea level. All above this level is called land, all below it sea. The rise of the land above this level is found to increase with the distance from the sea, forming the general elevation, the ever descending bottom of the sea constituting the general depression. These general elevations and depressions bear the same relation to our whole planet that special elevations and depressions do to limited tracts. It is the alternation of mountain and valley which modifies the continent, as also the bottom of the sea. *Pl.* 53, *fig.* 9, is a submarine section of the Straits of Gibraltar, *fig.* 10 a section taken between Tarifa and Alcazar on the Spanish coast.

1. *Mountains.*

The height of mountains, as well as the depth of valleys, varies to an extraordinary degree. It is man, not nature, who limits the almost imperceptible transition from the low plain to the highest mountain, by his artificial definitions. As, however, it is necessary to have some standard of comparison, it is customary to call an elevation of 100 feet or less, a hill; one under 3000 feet, a low mountain; one under 6000 feet, a mountain of medium height. Anything beyond this last limit is known as a high mountain. In measuring the heights of mountains it becomes necessary to determine the length of a line supposed to be let fall from the summit to the extended level of the sea. This line evidently expresses the relative heights of mountains, or their respective heights above the level of the sea. The relative height must be distinguished from the absolute, or that of a mountain from its summit to its base. For measuring heights of mountains

the theodolite is the most appropriate instrument, being capable of a very accurate determination of angles. If a station be selected from which the summit of the mountain in question can be observed, and the angle measured which the line of direction to the summit makes with the horizontal, and the horizontal line be measured towards the foot of the mountain, and the angular elevation of the top again taken from the other extremity, then we shall have all the data necessary to a trigonometrical determination of the point in question. The more usual instrument for measuring heights is, however, the barometer, the mercury in which stands at a different elevation with every difference in the distance from the level of the sea. The apparent simplicity of this method is nevertheless affected by several modifying causes, as the amount of moisture in the air, the temperature, the character of aerial currents, &c.

Every mountain may be divided into the top, summit, or head; the middle, face, or body; and the bottom or foot. The plane on which the foot is supposed to stand is called its base, and the faces of the mountain are formed by the declivity or slope.

The mutual relations in which the single parts of the mountain stand to each other determine its form, and of this we distinguish two principal types. Mountains proper are those whose length and breadth are pretty nearly the same, mountain ridges those whose length considerably exceeds the breadth. True mountains exhibit considerable diversities in their external forms; sometimes they resemble a segment of a sphere or paraboloid, sometimes a bell, a cone, or a pyramid. These various forms are not so uninteresting as might at first be supposed; the external appearance in itself may not, indeed, indicate any fact for geognostical consideration, it may, however, illustrate the peculiar relations existing between external form and the kind of rock. The generalization has been made, that the same rock species, when in not too inconsiderable quantity has constant external features, so that a practised eye may, in many cases draw an accurate inference as to the character of a mountain from a far distant view of it. Thus granite generally assumes the form of a spherical segment, trachyte that of the bell, while volcanic masses occur in the shape of a cone. The differences which exist amongst mountain ridges may have reference either to the ridge itself, or to the vertical cross-section. In the first point of view we distinguish between straight and curved ridges; in the second, between a circular, a parabolic, and a roof-shaped cross-section. In considering the slope of a mountain the geognosist first investigates the angle which it forms with the horizon. This angle, capable of infinite variation, is exceedingly difficult to ascertain, even approximately, without instruments, its determination being very much exposed to optical illusions. It becomes necessary to set artificial boundaries between the most frequent angular differences, and to express them by artificial appellations.

There may be modifications in respect to the continuity of the declivity, which contribute in great measure to the character of the mountain. This may either be uniform and uninterrupted, or may have a stairway or terrace

form: it may be cut up by furrows or intersected by ravines. The foot of the mountain, which in its slope and expansion may exhibit considerable diversity, experiences on the whole the same variations in the angle of inclination as the descent; this angle is, however, different from that of the body. The summit or top also varies much in shape in different instances; it is either acute, sharp, jagged, hunch-backed, rounded, flat, hollowed, or saddle-shaped. It is the manifold combinations of the different shapes of head, sides, and foot, that give such diversity to the appearance of mountains, and render it possible that mountainous regions may appear different in different places; each individual mountain may thus excite a fresh interest in the mind of the observer.

2. *Combinations of Mountains into Mountainous Regions and Ranges.*

It is very seldom that mountains occur entirely isolated; it is only single volcanic cones that are elevated abruptly from the midst of a plain. In by far the greater number of instances they are united into groups, and brought together in the most varied manner. In most cases mountains are arranged into what we call mountain chains. The mountain chains may extend in one or several directions; they may vary in length, breadth, height, and connexion. We can generally detect characteristics in the mountains which permit a distinction into two principal sections. They exhibit, with respect to the collocations of the mountains, either a certain want of system, or an arrangement according to definite laws. The first appearance is presented in very many hills or mountainous regions, as, for instance, in the extinct volcanic district of Auvergne (*pl.* 45, *fig.* 2), while the latter, which is of much higher interest, is a peculiarity of the mountain range proper. Most generally mountains occur, one after the other, so as to form a mountain range of greater longitudinal extent than lateral. This is the mountain chain as distinguished from the mountain group, which is of tolerably equal dimensions. The Hartz Mountains afford an illustration of the combination of both forms. Mountain chains are more frequently met with than mountain groups; this, however, does not appear to be the case on all the planetary bodies, as we may readily convince ourselves by an examination of the moon through a telescope. The immense number of volcanoes, with vast craters, in which again cones of eruption arise, are not to be mistaken in these mountain groups. In a mountain range there is always one part which can be distinguished as possessing the highest level; this is called the principal ridge, its highest portion being called the comb or crest.

Mountain ranges, like single mountains, exhibit a slope equal to the mean value of the angle of inclination for the individual mountains. In comparing the parts of a system of mountains with those of a single mountain, we shall soon find that a parallel cannot be drawn throughout, but that in the former there are parts which do not similarly occur in the latter. Examples of these are to be seen in such systems as Monte Rosa, where the mountains

are grouped concentrically, as also the mountain heights, single portions shooting up here and there independent of the rest; plateaux or planes, often inclosed by the highest mountain peaks, and at a great elevation above the level of the sea, passes, elevated extents of land lying between mountains connecting opposite slopes, and thus producing a saddle form. A pass of this kind occurs on the St. Gothard, lying 6390 feet above the level of the sea, and bordered on both sides by mountains over 9000 feet in height. Here belong also the plains found on slopes of the mountains, as also the spurs which separate and run out from the body of the system.

Mountain crests are very generally (especially in mountain chains) ranged one after the other, thus giving rise to a narrow linear extension, called a mountain range. Such ranges occur in greater or less number in the same mountain system; they generally run out from one, more rarely from two or more primary ranges, these latter being then parallel to each other. In mountain chains the primary range is called the longitudinal, from which run out the lateral or terraced range or spur. We must also distinguish secondary ranges from the tertiary ranges. The ranges in mountain groups have generally a radiated direction. The height of the secondary ranges usually decreases with the distance from the primary range; this, however, is not always the case.

The connexion of mountain systems, when such exist, may be effected either immediately or indirectly. Mountainous or hilly land is generally the link which effects the union; it is thus between the Hartz and the Thüringerwald, between the Alps and the Chain of Jura. Where the outposts of one mountain system extend their arms into the valleys of another, the alliance is immediate; this is the relation between the Alps and the Appenines. Just as the forms of mounts and mountains are exceedingly various, so is it in respect to their external features. Plane surfaces alternate with those that are hilly, rough, and full of cavities; steep rocks with deep fissures.

3. *Valleys.*

As valleys are produced by mountains, it is natural that the peculiarities of the former should depend on those of the latter. At first glance into a valley two features are readily recognised: one of these the bottom, and the other the walls or sides, produced by the inclosing mountains. If we suppose a valley to be intersected by a plane at right angles to its axis, many diversities will be observed in this cross-section. The bottom of the valley is either straight or curved, occurring both convex and concave. In respect to longitudinal extension, valleys are either horizontal or inclined at various angles. An interesting phenomenon is presented by the successive descents in valleys, seen particularly in the transverse valleys (those which intersect the longitudinal valley of a mountain chain nearly at right angles). The occurrence of many waterfalls is intimately connected with this feature in valleys. Valleys are sometimes completely inclosed by mountains,

in which case they are generally circular or elliptical in shape, and are often converted into lakes, as is the case with Derwentwater, or the Lake of Keswick (*pl.* 51, *fig.* 2), in the county of Cumberland, England. Valleys which are half inclosed, generally extend far in a longitudinal direction, and have but one outlet, while the open have this on two sides. The latter, the open, are also called valleys of interruption, as they generally connect two longitudinal valleys, and therefore break through, as it were, the separating ridge.

The study of the relations in which the valleys of a mountain system stand to each other, is of extraordinary interest, this being increased in many cases in proportion as their character enables us to recognise a certain causal connexion. This, however, can only be elucidated after a close comparison of the relations of stratification has been instituted; we shall therefore first consider the relations in which valleys stand to mountains and to mountain ranges. Those valleys which lie within the limits of a system of mountains are called mountain valleys, in distinction from outer valleys lying to the outside of the same systems; both, again, differ from intermediate valleys which separate two contiguous systems. Since valleys are bounded by mountain ranges or spurs, and as we distinguish three kinds of these, it naturally follows that the valleys will also differ among themselves. Accordingly we separate primary or longitudinal valleys from lateral or cross valleys, as well as from secondary valleys, these being all bounded by the corresponding mountain ranges. Longitudinal valleys have generally a considerable extension in length, and but little in breadth, the surface presenting much uniformity of appearance. The case is precisely the reverse with the cross and secondary valleys; these, on the whole, are shorter, and alternately expand and contract, often run out into ravines, their walls being not unfrequently formed by remarkable rocks. We also find here the peculiar terrace-like character, with the accompanying waterfalls. In mountain chains the corresponding valleys exhibit a more or less parallel arrangement; in mountain groups they exhibit a radiation more or less complete. A phenomenon of no very rare occurrence is the mutual intersection of valleys at different angles.

4. *Plains.*

When valleys are very broad they pass into plains, no well defined limit between the two being possible. The character of plains may experience modifications by taking their boundaries into consideration. Under this point of view we distinguish coast and interior plains. The former are such as are bounded on one or more sides by the sea, the latter being inclosed on all sides by mountains or mountainous land. These, however, are rather geographical distinctions; to the geologist the division into depressed plains, plains proper, and elevated plains (plateaux), is of much more importance. The first lie below the level of the sea, the second are elevated slightly above it (as the coast of Holland), and the third, sometimes called table-

lands, are at a considerable height above the sea, as in the plateaux of Bavaria and Mexico. The same difference exists between the level of inland waters and that of the sea. Thus the surface of the Caspian Sea is about 31ft. below that of the ocean, and that of the Dead Sea about 1300ft. The bed of the Jordan, in part, lies below the level of the Mediterranean. This is unquestionably the case with the sea of Tiberias. *Pl.* 45, *fig.* 3, exhibits a section of Judæa through the basin of the Dead Sea, from which these relations may be readily seen. In general, however, inland bodies of water are higher than the ocean, at times very much higher, as instanced by Lake Titicaca in Peru, existing at an elevation of 12,800ft. (*pl.* 45, *fig.* 12). The size of the lake or sea generally decreases with the elevation.

5. *The Interior of Mountains.*

We turn now to a brief consideration of the interior of mountains, after having thus examined the peculiarities of their external form. The simple fracture of a stone, of a naked rock, and especially mining operations, soon show us that the interior does not consist of a simple homogeneous mass; on the contrary, we perceive that various rocks alternate with each other, and are split up into smaller parts of a great mass. We see cracks crossing through one another, and often in such a manner as to form subdivisions of definite form. These portions often exhibit a certain goniometrical character, comparable with crystallization, which comparison, however strictly speaking, is not allowable. If we consider the real character of a crystal, we shall soon find that no analogy exists between it and such a separating fragment, further than that of general external form, the edges, corners, and faces, not obeying strict crystallographical laws. The relative positions borne by these masses of separation or cleavage to each other are known as structure.

6 *Cleavage of Rocks.*

Masses of cleavages present themselves under two points of view, as angular and rounded. The latter are produced when the planes of cleavage return into themselves, these shelling off on further cleavage. Whether the cleavages be straight or curved, if they occur in one plane, this is called the plane of cleavage, which may extend over small spaces or through entire masses. The cleavage of rocks occurs in various degrees of completeness. The application of force is sometimes necessary to separate the cleavage masses, others are entirely separated, and in other cases, again, the spaces of separation are no inconsiderable cavities. In dealing with cleavage it is necessary to ascertain whether such be essential or non-essential; whether it stand in prime connexion with the character of the interior or not. The non-essential are entirely accidental, and are

called joints. In the actual structure of rocks we must necessarily distinguish true cleavage from stratification.

True cleavage never extends to so great distances as stratification. The parts into which cleavage planes divide rocks are referable to a rounded and an angular form. Of the former class we have the sphere, the spheroid, the ellipsoid, the elliptic spheroid, and the indeterminate surface. These forms frequently exhibit a concentric cleavage, as seen in basalt, granite, porphyry, &c. (*pl.* 43, *fig.* 23). Most frequently, however, the cleavage is plane.

The angular forms are either indefinite, columnar, or parallelopipedal (prismatic). The first class comes nearest to the spherical form. Thus lumps of menilite are found in adhesive slate (Jameson) coming very near to an aggregation of spherical segments (*pl.* 43, *fig.* 22). The columnar form is most frequently seen in rocks which have passed from a melted liquid condition into the solid. Basalt is especially adapted for the study of columnar structures. The six-sided prism must be assumed as the primary form from which the three, four, five, seven, &c., have been derived as irregular or imperfect developments. In basalt a sphere is not unfrequently combined with the column, easily recognised in the alternate bending in and out of any two edges of the column, and their accompanying thinning and thickening. A single column is generally divided into numerous joints by transverse cleavage (*pl.* 53, *fig.* 11), the spherically convex end of one joint fitting in the spherically concave end of the next (*pl.* 53, *fig.* 13). When the spherical segment is somewhat greater it forms projecting sharp corners to the edges of the prisms, a feature not unfrequently seen in the basaltic pillars in the Island of Staffa. Entire mountain masses sometimes exhibit this structure, which is especially peculiar to lava currents, as shown in *pl.* 43, *fig.* 24. The columns often consist of small plates inclined irregularly to the principal axis at different angles (*fig.* 25). Porphyritic columns occur in this manner on the Wachenberg near Weinheim. A peculiar phenomenon is sometimes exhibited when a melted mass, subjected to great pressure, has been forced up so as to fill a crack or fissure in the rocks. On cooling, the columnar cleavage arises, and the extremities of the columns stand at right angles to the sides of the fissure. Thus, if the fissure be vertical, the columns will be horizontal, and vice versâ. *Pl.* 43, *fig.* 16, is intended to elucidate this phenomenon. In the vertical fissure, *b*, the columns are horizontal, while the horizontal masses below *c* and *d* have vertical columns. In large masses this rule does not seem to hold good, the columns being combined like billets of wood in a charcoal pit, or else lie grouped irregularly, one upon another. This is shown very clearly in the Island of Staffa (*pl.* 49, *fig.* 7).

As the columnar form is peculiar to rocks of igneous origin, so the parallelopipedal is restricted almost exclusively to those which have been deposited from water. Both the rectangular and oblique parallelopipedons occur; the former of cubic, pillar, square, and tabular forms.

7. *Stratification.*

Stratification, which always extends over greater distances than true cleavage, is peculiar to rocks deposited from water. Plutonic rocks are sometimes subdivided in a manner bearing a great resemblance to stratification; the affinity in structure is, however, only apparent, not real, the subdivisions being merely a tabular cleavage of columns or parallelopipedons. Granite often presents this appearance, as shown in *pl.* 43, *fig.* 12, where the corners and edges of the separated portions have been rounded off and weathered away by atmospheric agencies. Stratification and cleavage may occur together, as is often seen in slate rocks, whose cleavage planes, parallel constantly to each other, intersect the planes of stratification at all angles.

The portion of rock included between two planes of stratified separation is called a stratum. The thickness of strata is exceedingly variable, and not unfrequently immense beds are found to alternate with quite thin layers.

The planes of stratification are generally straight, although not always of great extent. At times their general direction is straight, with occasional undulations, curvings, and contortions (*pl.* 43, *fig.* 8). These bendings and foldings, which sometimes give rise to the formation of caves (as in the grotto of Jupiter on the Island of Naxos, *pl.* 51, *fig.* 8), often run into the finest crumpling, as may frequently be observed in clay slate, this rock being, for other reasons, especially adapted to the study of stratification. Silicious slate is not unimportant in this respect, a complicated stratification being peculiar to it. The strata are often entirely curved (*pl.* 53, *fig.* 8, representing clay slate strata on the coast of Scotland, and *pl.* 43, *fig.* 9, strata on the coast near Wapness, not far from Guns-Green), this condition being more interesting than a partial flexure. There are two principal differences in this respect, according as the opening of the bend is above (*pl.* 43, *fig.* 5) or below (*fig.* 7); as also, whether the bend be arched or angular like the roof of a house. When the opening is turned up we have a trough: when below, a saddle. Troughs and saddles generally succeed each other, as seen in great perfection in a section of Brittany, between Rennes and Nantes (*pl.* 46, *fig.* 3).

Strata frequently exhibit a change in their position, so that one part of the same layer stands at a higher or lower level than another. When the variation is inconsiderable it is called dislocation; where of greater amount, displacement. These frequently stand in such connexion with veins and fissures as to render it not unreasonable to ascribe all to the same system of forms.

8. *Arrangement of Strata.*

The position of planes of stratification is either horizontal, vertical, or

inclined at various intermediate angles. The horizontal position is of least interest, what little it possesses arising from its relation to the inclined. In inclined strata the geognosist has first to deal with dip or inclination and strike. The dip of a stratum is the angle which it makes with a horizontal plane, and the strike the angle made by a horizontal line of the stratum with the meridian. The direction has also to be considered in the dip. For determinations of dip and strike, the mining compass, with a pendulum and graduated arc attached, is the most convenient instrument.

The planes of stratification are either parallel or convergent to a greater or less degree. When the latter is the case a fan-shaped stratification is presented, in which the planes of stratification all appear to converge towards one point, diverging from one another in the opposite direction.

9. *Relation of Stratification to Mountain Masses.*

The relation of stratification to mountain masses is of great importance, their whole character depending on it. Mountains and valleys are arranged similarly with their predominant strata. It has already been mentioned that stratification is peculiar to rocks which have been deposited from water; it will therefore be readily understood that the general arrangement of strata must be horizontal, or not very far from this position. That all strata, however inclined, contorted, broken, or disturbed, were really once horizontal, is a proposition which admits of no doubt, with the powerful reasons in its favor furnished by geological science. The question immediately presents itself, however, by what means have the strata been elevated? What kind of force has produced such effects? The answer to these queries we find in the investigation of those rocks already ascertained to be of igneous origin. The peculiar manner in which these latter occur, the relation in which they stand to the stratified masses, and the alterations they effect in the petrographical condition of the same, fairly authorize us to look upon such igneous masses as closely connected with the phenomena in question. Thus, on the coast of Dorsetshire we shall find beds of chalk upheaved by basalt (*pl.* 52, *fig.* 8). An upheaval of rocks of the Jura (*pl.* 43, *fig.* 13, *b*, *c*, *d*) by abnormal masses is seen near Freiberg in Breisnau, and in the canton Bern (*fig.* 14). This will be referred to more fully hereafter; at present our main object is to consider the relation of strata to mountain masses. To do this properly it would, perhaps, be convenient to name valleys according to their origin. The difficulty here, however, would be in the introduction of theoretical views into nomenclature, which might be embarrassing to a beginner in science. Thus, longitudinal valleys might be called valleys of elevation, their formation being contemporaneous with the elevation of the mountains. A longitudinal valley is generally so constituted that its strata are parallel to the slope of the mountain which has given rise to it; thus, if we suppose horizontal strata to be elevated by two forces acting parallel to each other, the valley will lie between the two mountain ridges thus produced. Single circular valleys

must also lie included among the valleys of elevation, where the strata lie around parallel to the mountain slope. An excellent illustration is found in the valley of Pyrmont (*pl.* 44, *fig.* 1), where the elevating mass lies under the strata, as of the variegated sandstone, without having broken through. Upon this lie the strata of the muschelkalk, *b*, and upon this, those of the keuper, *c*. The strata *b*, as well as *c*, occur on both sides, and were formerly continuous, having been separated at a subsequent period. When the strata were too brittle to admit of a considerable bending, they have been broken. Thus, while in this fissure a steep descent on both sides, along the axis of elevation, must exist, on the other sides, in a direction transverse to this axis, the slope will be more or less gentle. These relations, of no unfrequent occurrence, are shown sectionally in *figs.* 2, 3, 4, and 5. In *fig.* 2, the elevating nucleus has broken through, the strata resting on it on each side. The steep declivities of the faces of the strata are turned towards the head of the nucleus, the planes of stratification lying parallel to the slope. In *fig.* 3, the mass of elevation constitutes only the base of the valley, as also in *fig.* 4, where the strata are of unequal thickness. Should an elevation of the latter kind take place under water, as seen in *fig.* 5, so that the strata project only on one side, the mountain chain appears to consist of one such lip, the other being concealed by the water. The strata may often slope so much along the nucleus, as that this shall occupy the higher level, as on the Brocken in the Hartz (*pl.* 43, *fig*, 15), where the ganite, *a*, lies higher than the strata, *b*, *c*, *d*, *e*, *f*, of the transition-slate formation. If the non-conformable mass be in great preponderance, the conformable may be torn entirely asunder. Valleys thus produced are called valleys of disruption (*pl.* 45, *fig.* 1).

Before we proceed further in this part of our subject, it may be advisable to mention a few of the technical terms employed in the consideration of stratification. The terms dip and strike have already been referred to. If we conceive a longitudinal force to act in upheaving a succession of strata, the line or plane in which the disturbed strata would meet if produced, is called the anticlinal axis or line. In other words, it is the line in a chain of hills or a valley from which the strata dip in two different directions. The synclinal line or axis is that along which opposite strata dip towards each other. When strata are parallel to each other, whatever be their dip, they are said to be conformable. When strata rest on the edges or faces of other strata, in such a manner as to render it evident that all are not of contemporaneous origin nor have been exposed to a simultaneous force, they are called non-conformable. An out-crop of strata exists when the edges of these strata have been elevated by the disturbing force so as to come to the surface. When strata have been broken or dislocated by some force, so that the continuity of the individual beds is interrupted by the sinking down or displacement of one of the portions, a fault is produced. When the fissure or split is filled up by injected igneous matter, a narrow wall is exhibited, called a dyke.

Valleys sometimes occur as excavations produced by the abrading action of currents of water. This fact can be readily ascertained from an exami-

nation of the stratification on opposite sides; this existing in the same plane on both sides of the valley (*pl.* 43, *figs.* 1 and 2). Such are called valleys of excavation or denudation. In *pl.* 43, *fig.* 3, the same stratum, *a*, is seen on the left-hand side much higher above the bottom of the valley, B, than on the right side, without any difference existing in the general direction. The determination of the true character of mountains and valleys from the nature of the accompanying stratification, however simple it may be theoretically, is yet very much embarrassed in practice, by the vegetation and surface soil which hide the subjacent rocks. In individual cases, however, this difficulty does not exist, and the whole problem can be solved at a single glance. These relations are beautifully seen in parts of the Mont Blanc chain, whose tabularly cleft rocks are presented with vertical fissures. Weathering causes the loss of considerable portions, as is often the case with granite and gneiss. In this way steep pyramidal rock walls are left, which form the boldest and most singular groups. Some idea of this condition of things may be obtained from an examination of *pl.* 44, *fig.* 10, this representing a view of the Mont Blanc chain from the Breverberg. Here *a* indicates the celebrated vale of Chamouny; *b*, Mont Blanc; *c*, La Mer de Glace, a glacier; *d*, the Bosson's glacier; *e*, l'Aiguille verte; *f*, le Dome du Gouté; *g*, la Montanvert. This character of rock surface exhibits a magnificent appearance when traversing whole ranges. The names of horns, needles, teeth, &c., given to the different projections by the inhabitants of the Alps, are derived from real or fancied resemblances. The vicinity of Bärschwyl in the Solothurn Jura, shows beautifully the manner in which the character of stratification influences the external form of a country. The strata are entirely denuded, and their relations to the mountain formations is evident at a glance (*pl.* 44, *fig.* 11). Mountain forms become remarkably modified when rocks of different petrographical character alternate with each other. Harder and more durable strata, *a* (*pl.* 44, *fig.* 12), alternate with others of much softer texture, or readier destructibility, *b*. The former remain standing in extended rock walls, while the latter disappear to a greater or less extent. Terraced valley slopes may be produced in the same manner (*pl.* 44, *figs.* 13 and 14).

10. *Accidental Separation of Rocks.*

The parts produced by accidental separation of a rock mass, or by fissures and joints, possess an undefined, irregular form. They are entirely incidental in their origin, and may either be confined to a small space, or traverse whole mountain masses. The fissures are of various sizes, from thin cracks to extended and sometimes wide gaps or fissures. Important effects sometimes accompany the formation of such accidental cracks and fissures. Whole mountain masses are often shattered, or otherwise affected, and debacles not unfrequently produced.

11. *Beds.*

A definitely limited rock mass, consisting of the same species of rock throughout, is called a bed, and mountain masses or formations are composed of a succession or superposition of such beds. These beds exhibit one primary difference, having reference to their relations of dimensions: they are either extended with tolerable uniformity in all directions, or else in one direction rather than another. In the first instance the components have a curved surface, or undefined angular form, while in the latter they approximate to the tabular. These beds are sometimes connected over extensive spaces, and sometimes they are interrupted. This interruption is either apparent or actual. The apparent is very interesting in a geological point of view; it especially occurs in trough formations. If we examine the map of the tertiary basin of Paris (*pl.* 44, *fig.* 6) and its section (*fig.* 7), we shall see that the chalk formation is interrupted at Bourges, Auxerre, Chalôns, Rheims, and Laon, by the tertiary masses, disappearing at Paris, Melun, and Orleans, and coming out again at Chartres, Tours, Le Mans, Evreux, Rouen, and Amiens. This, however, is not actually the case; the chalk is only covered by the tertiary, as seen by the section, where 1 indicates the tertiary, 2 the chalk, 3 the succeeding Jura formation. The bed 2 thus forms a trough or basin, in which the bed 1 has been deposited, hiding the other to a certain extent.

The beds are either in immediate contact, or they are more or less separated from one another. In the latter case they are separated by the interposition of an inconsiderable mass. By their mutual contact they are brought into layers, which generally follow a definite order. Before considering this latter point it will be necessary to pay some attention to the mode of bedding.

Beds of tolerably equal dimensions are often bounded by others only on one side; and, again, may be inclosed on all sides. The former then not seldom project from the latter. Most frequently the beds are laid, one on top or after another, forming various angles with the horizon. This condition of imposition or combination is known as the order of succession; thus we say the bed A (*pl.* 43, *fig.* 4) succeeds B, B succeeds C, C succeeds D, &c. In *fig.* 3, also, *a* succeeds B. The study of this order is of great importance in the consideration of stratified rocks.

When a plane of arrangement is more or less horizontal, and the beds lie one above the other, they are said to be imposed, or to cover one another; if this be not the case, they are applied. When beds come one after the other, we have to examine whether the applied bed lies at an equal, a higher, or a lower level.

When beds are imposed, it not unfrequently happens that they decrease as they ascend, thus giving rise to the formation of terraces like the Trapp Mountain on the Scandinavian peninsula. Overlapping exists when one bed overlies two or more others. Thus, if a bed of muschelkalk rest

against one of sandstone, and both be overlaid by a bed of keuper, then the latter is said to overlap the others.

As already mentioned, stratifications are divided into conformable and non-conformable. Conformity may exist either in a parallelism of the planes of stratification (as *pl.* 43, *figs.* 3 and 5), or in an equal extension of the strata, as *a* and *a* (*fig.* 3). Non-conformity exists where the strata neither exhibit parallelism nor fall in the same plane, as seen in *fig.* 6. Here A, B, C, D, have different positions from F and E, although A, B, C, are conformable to each other, as also are F and E.

12. *Order of Succession and Relative Age of Rock Beds.*

Long continued and careful observation has shown that a constant order exists in the succession of different rocks, and one that is never departed from. This is especially the case with the stratified masses (those formed by successive deposition from water). Thus we find strata of muschelkalk lying on variegated sandstone, and keuper on muschelkalk, and this succession occurs wherever these rocks are found; if they were to be continued round the earth, they would embrace it concentrically, like the coats of an onion. This condition, to a certain extent, would, in fact, have existed, but for the interference of volcanic or volcanoid actions; these have elevated large islands, and even entire continents, from the bottom of the former universal sea, and thus prevented any further deposit on these portions of the ancient ocean bed. It is only where water occupied large basins that this could occur. The strata thus formed we find to be interrupted by non-stratified rocks, these sometimes spreading above them, just like the lava streams of modern times, which, after filling up deep ravines, run over the edges, and are diffused over the surrounding country. The correctness of this analogy is shown, not only in the above relation, but also in the petrographical condition and structure of ancient and modern igneous rocks. It is upon these diversities of existence of the different beds of rocks that the difference between normal and abnormal masses has been grounded (exogenous and endogenous of A. von Humboldt). The former are the really stratified, the latter those which were once in a melted condition. Inasmuch as we are permitted to assume that all normal masses have been deposited from water, we are entitled to consider their order of succession as indicating their relative antiquity; a rock is then older than the one above and younger than the one below it. An absolute determination of the antiquity of strata is impossible, even approximately; this much is, however, certain, that the oldest proclaims an age which vastly exceeds that of 6000 years.

To determine the relative age of masses, which, genetically considered, must be supposed to have been forced up from below, it is necessary to pursue a different method; we cannot, of course, determine from the actual succession in this instance. In this case we must have reference to the penetration of one abnormal mass by another, and that of normal by

abnormal. We can estimate the age of one abnormal mass only in reference to another or to a normal. That phenomenon of interpolation is of not unfrequent occurrence, being often seen in some basalts. An instance of this is seen in the Electorate of Hesse, near Eschwege, where a basalt has pierced through the variegated sandstone, and overlies it. This relation has been revealed by an extensive stone-quarry which affords an excellent view of the whole circumstance. The sandstone has been discolored in the vicinity of the basalt, and melted with it at the immediate surface of contact. The basalt is thus newer than the variegated sandstone, or the abnormal younger than the normal. The same is also the case in the Meissner mountains in Hesse, where basalt has broken through the tertiary brown coal, and poured up over the top. The penetration of abnormal masses by others also abnormal, is likewise of frequent occurrence. Thus, in the vicinity of Heidelberg, granite may be seen which is traversed by veins of granite of entirely different petrographical character, of another color and other grain. The granite traversed must necessarily be the older of the two. In volcanic regions, also, we frequently see trachytic rocks traversed by basaltic, or older lavas by younger, as shown in *pl.* 43, *fig.* 11. The dark portion is an older abnormal rock, pierced by a younger (the vertically lined portion), and together with the dotted normal elevated by it. The alterations effected by abnormal masses in the stratification of normal cannot readily be mistaken. By the elevation of the former the strata of the latter have been upheaved, broken, and sometimes entirely inverted. *Pl.* 43, *fig.* 15, is a profile of a portion of the Hartz mountains, in which *a* represents the Brocken, consisting of granite, which has upheaved and pierced through the normal transition slate, the individual strata succeeding, each in precisely the same relative order, and of the same size on each side. In this instance, as in many others, it is impossible to overlook the agency of the granite. By means of such elevations older strata are brought to view, and man enabled to ascertain facts with reference to subjacent beds, which must otherwise have remained buried in perpetual obscurity. Did the different layers envelope the earth with the regularity of the coats of an onion, it might be possible to pierce through one, or at most two of these, by mining operations, and no more. In the present condition of things, however, we find an entire succession of rocks revealed, with a limited extent of surface, which otherwise, at depths of entire miles, would have been beyond our ken.

13. *Formations, Groups, and Systems.*

If we consider the different rock beds, with respect to their constitution, we shall soon find that the most important are represented by only a few species of rocks; limestone, sandstone, clay, and the marls, are those which occur most frequently. Nevertheless, they exhibit such decided characters in their different relations, as to render it impossible to mistake them in certain groups, and to fail of coming to the conclusion that they were

formed within a certain definite period of time. These characters have reference to structure, to condition of aggregation, and to the included fossils or organic remains. Such a combination of beds, exhibiting these features, is called a formation.

In such a formation we distinguish with reference to the importance of the included beds; principal measures, which always exist; secondary, which seem to accompany the last, and generally are of no great extent; and subordinate, which do not always occur in the formation, but are limited to restricted spaces here and there. Single series of deposits within a formation, agreeing in more special characters, give rise to another distinction into groups; these, not unfrequently, again being composed of individual rock species, which, in turn, may be built up of strata. On the other hand, entire formations may stand in a certain relation to each other, giving rise to their collocation into systems.

Although a formation or a group generally possesses the same petrographical character in all parts of the earth, yet there may be exceptions in certain cases. Certain groups of strata may be entirely different from others, and yet be of contemporaneous origin. When such an abnormal condition occurs we have to deal with a representative or a geognostical equivalent.

14. *Subordinate Strata.*

A rock measure is rarely so constituted as to consist entirely of the same geognostical species; measures also frequently occur which must be considered as subordinate, whether standing in a definite structural relation with the primary measures or not. In the former case they lie between the beds of rock connecting them with each other.

The ordinary subordinate beds, or those included between the approximately parallel surfaces, exhibit, in general, the same relations as were found to exist in the case of stratification. Thus certain coals and many iron ores occur in such beds. These are generally of nearly equal dimensions, and approximate in a greater or less degree to the spherical or spheroidal form. Forms of indefinite surface also occur, and this not very rarely.

The ore beds of the north, as the copper and iron pyrites' beds at Fahlun, the ironstone at Arendal, &c., occur in masses of the above-mentioned character.

Here belong also those matters which fill fissures and clefts in rocks. This matter may be of very different character in different cases; it may have been introduced by a washing in from above, or by the injection of abnormal matter from below (*pl.* 53, *fig.* 14). These two varieties are readily distinguishable. The subordinate beds already considered, all stand in a certain connexion with the rock mass; there are others, however, in which this is not at all the case. These are of various shapes, ellipsoidal, spherical, &c., and vary in size from an inch to many feet. They are either partly or entirely filled up. The masses which fill the spaces

frequently have a somewhat definite structure, variously colored layers, conformable to the walls of the cavity, as in *pl.* 43, *fig.* 19, or lying horizontally, as in *figs.* 17 and 18, alternating with each other, and not unfrequently leaving cavities at the centre, which become filled with crystallizations of various mineral substances. The same thing occurs in amygdaloid (*fig.* 16), a rock containing spherical, *a*, ellipso-spheroidal, *d*, almond-shaped, *b*, cavities, filled with calcareous spar, these varying between the size of a few lines and several inches. Stalactitic formations are also met with in such cavities, as in *fig.* 17. The contents have most probably been introduced by infiltration. It is well known that water containing carbonic acid gas in solution, can dissolve carbonate of lime, of which calcareous spar consists. This solution, penetrating into the cavity, there deposits its mineral matter. It may be asked whence comes the carbonic acid of the water? The question is not difficult to answer when we recollect that a small proportion, about one volume in 2000, of our atmosphere, consists of carbonic acid gas, which, being dissolved by the descending rain, is brought into contact with calcareous rocks. That water is capable of penetrating solid rocks, is well shown by the amount contained in stone dug out of the ground, unless these be of a glassy character, as is the case with obsidian, pitch-stone, &c. The infiltration of water through the solid roofs of caverns is another instance. Spaces nearly or entirely filled up, sometimes clearly exhibit the point at which the water penetrated. The continuity of the layers is seen to be interrupted at this place, as in *figs.* 18 and 19; *a* represents the layers which leave an open tube at *d*, through which the infiltration took place. Rocks and mineral substances occur in such spaces as subordinate beds of the most different extent and character. The character depends upon the accompanying minerals, some of which, as iron pyrites, copper pyrites, various iron ores, &c., may be advantageously worked by the miner. Small cavities of the kind are called nests. They are either isolated or connected, and not unfrequently stand in such relation to the associated rocks, as to form a continuous succession of beds parallel to the latter.

15. *Veins.*

Of the subordinate members of various groups of rocks, those deserve particular mention which, while exhibiting a great preponderance of one dimension over the other two, stand in no connexion with the structure of the rock itself. Veins are of this character: they belong to the most important forms exhibited by the earth's crust, since it is from them that most of the metallic ores and native metals are derived; their interest, however, does not depend entirely on the fact of their containing these useful or valuable substances, but also on the mineralogical beauty of crystallization and form frequently presented by their contents. Veins break through and traverse the stratified and amorphous rocks at various angles, rarely following the lines of stratification or cleavage, and then only

for a short distance. There appears to be no regular law to which the course of veins is subjected : they seem to pursue their own course, without being affected in the least by the hindrances which stratification would seem to present. Most mining operations have reference to the following up of veins, as may readily be seen in almost any mine other than one of coal: here the substance sought for always occur in beds, layers, or strata.

The shape of a vein can only be ascertained by working it. Its dimensions in a horizontal direction may thus be determined; but the matter is more difficult with reference to its vertical descent. Little is known of the character of veins at great depths, and this ignorance prevents much knowledge of their true character. The upper portions of veins, however, can be readily investigated; they are either exposed to view at the surface, when the incumbent detritus has been removed, or else they wedge out before coming through the containing rock. The horizontal course of a vein, with reference to the meridian, is known as the *direction*, and the angle of descent, formed with a vertical plane, is called the *hading* of the vein. In most cases the vein comes to the surface, where it may project like a wall. In reference to the distribution of the vein, three principal parts are distinguishable, the central and two wings. In a very few cases the vein is everywhere uniform; it is more generally ramified, and runs out into threads. The wings may vanish in a similar manner, although they are sometimes found to be cut off by *faults*. This cutting off may be effected by dykes of igneous matter or by other veins. In such instances the vein may, in most cases, be recovered on the other side of the displacing body, although not always in the line of continuity.

A vein frequently swells out in parts of its course, so as to occupy a considerable space. The masses filling up these spaces are termed *lodes*.

The matter filling up a vein is called the matrix or gangue, and may be composed of very different substances. These consist of mineral bodies, of mixtures of mineral species which do not occur as rocks, of true rocks or of their mixtures, either loosely aggregated or cemented by some other substance, thus forming a true breccia. A vein may be filled with a metallic ore, mixed with some non-metalliferous substance, the latter being termed the gangue. While veins containing non-metalliferous matter exclusively are of rare occurrence, it is still more seldom that they are found occupied by native metals. This latter case occurs more frequently in the copper mines of Lake Superior than anywhere else. Gangue, or matrix and ore, are most frequently found together.

The relative ages of veins, as of abnormal rock masses, must be determined by their mutual penetration. Investigations of this kind can only be carried on in extensive mines, and even there the results are by no means satisfactory.

The filling up of the vein is either entire or partial. The former case is peculiar to abnormal masses, such as granite, syenite, diabase, trap, and porphyry. The occurrence of druses is intimately connected with the partial filling of veins. These are hollow spaces of ellipsoidal form, their major plane of intersection parallel to the plane of the vein (*pl.* 39, *fig.* 81).

They are of different, often very considerable size, and are sometimes lined with the most magnificent crystallizations. A large druse was opened at Andreasberg a few years ago, and brilliantly illuminated with torches. The splendor of the appearance produced by the reflection of light from the thousands of crystal faces is described as having been almost overpowering. Such drusy cavities most generally occur towards the upper extremity of the vein, decreasing in number with the descent.

Ores are said to lie *disseminated* in the gangue when they are interspersed in small particles, and *imbedded* when aggregated in larger masses. Gangue and ore may likewise alternate in layers parallel to the sides of the vein, as seen in *pl.* 43, *fig.* 20. Here the layer *a*, immediately lining the cavity of the vein, consists of brown blende; the succeeding one, *b*, of quartz; the layer *c*, of fluor spar; *d*, of brown blende again; *e*, of barytes; *f*, of radiated pyrites; *g*, of barytes; *h*, of fluor spar; *i*, of radiated pyrites; *k*, of calcareous spar; and *l*, of a drusy cavity, lined with crystals of calcareous spar. In some veins the ores include spheroidal masses of the gangue, so as to present an annular appearance. An argentiferous galena of this character occurs at a mine not far from Klausthal in the Hartz, for the above-mentioned reason called "ring and silver thread."

The connexion existing between mineral veins and the inclosing rocks is quite different under different circumstances. Sometimes the former separates readily from the latter, either owing to a natural absence of connexion, or to a decomposition and weathering of the outside. At other times the vein mass is so intimately united with the rock as to cause great difficulty in the separation.

When a vein is not precisely perpendicular (a rake vein) it may either *hang* (form an obtuse angle with the descending vertical) or *lie* (form an acute angle with the vertical).

A very remarkable relation sometimes exists between the vein mass and the including rock, with respect to their internal and external peculiarities; these relations, however, cannot be combined into any definite system. The principal facts of the kind are, that the vein, on the whole, is weak in proportion to the hardness of the rock; also, that the same vein may continue through different strata, and be of different contents in different rocks, and that the gangue may or may not exhibit an affinity to the rock.

Neighboring veins, which run more or less parallel, communicate only by their ramifications or threads; they may, however, intersect each other at various angles, these being either right or acute and obtuse (*pl.* 39, *figs.* 85, 82). The veins sometimes intersect, run together for a short distance, and then separate, as seen in *fig.* 83.

When such intersections take place it is in most cases possible to distinguish the intersecting from the intersected. A vein, A, cut by a vein, B, sometimes is continued in precisely the same course; it frequently, however, experiences a displacement to one side or the other of the original direction, termed a shift (*fig.* 84). The continuation of the intersected vein on the opposite side may narrow or expand (*fig.* 85); it may ramify

(*fig.* 86), the ramifications being sometimes occupied by ore of different richness from that of the rest of the vein. It occurs not unfrequently, that the vein B, crossed by the vein A, is entirely cut off (*fig.* 87).

Veins sometimes are found which consist of the combination, at every possible angle, of innumerable threads, weaving together entire mountain masses. This is the interlaced vein in which tin ores generally occur.

16. *Theory of Veins.*

The true character of mineral veins is still involved in great obscurity. There can be no doubt that veins are the filling in of splits, fissures, or cracks, and that the origin of many veins, especially those which occur in abnormal masses, can be satisfactorily explained. The answering of the question, as to how these cracks arose, and in what manner they have been filled up, presents difficulties so great, that a long time must probably elapse before they are entirely removed. Many of the theories suggested are untenable on their very face; and others, not quite so preposterous in themselves, require more satisfactory verification than they have yet received.

The assumption that vein fissures owe their origin to volcanic actions, among which we enumerate earthquakes, and the elevation of plutonic, volcanic, and volcanoid masses, possesses a great show of probability, since entire systems of veins may be reduced to certain points of elevation.

Mount Etna furnishes remarkable illustrations of this kind. The veins belonging to one period of eruption all run more or less radial towards the eruption cone of the principal crater; these veins thus belong to the principal crater. Now there are many systems of veins, in which each vein has reference to the same point, or stands in such similar connexion with certain points, as to compel the supposition that a principal crater must at one time have formed the centre of such a system. The phenomenon is not rare indeed of a volcano so choking up its old crater, as that the molten matter in its elevation has been compelled to throw up a new crater, in connexion with whose formation new systems of cracks make their appearance. This explains the fact that veins are of most frequent occurrence in those primary rocks which are most intimately in communication with abnormal masses; ore veins are also frequently found on the limit between normal and abnormal masses, and are known as contact veins.

The history of the hypotheses adduced to account for the phenomena of veins is much the same with that of the suggestions with reference to the origin of terrestrial volcanoes. The most improbable and exaggerated hypotheses have been propounded in this respect, many of them pure fancies of the imagination, supported on imperfect observations, while others again possess a greater amount of plausibility, and even in some cases establish laws which yet cannot be considered as applicable to all cases. Thus we may, with propriety, assert that veins of calcareous spar in

carbonate of lime, veins of gypseous spar in compact gypsum, &c., have been filled by infiltration from the accompanying rock. This, however, may not be said in regard to metallic ores, or of such veins as contain native metals, since we cannot understand what medium could have dissolved these substances, which, besides, we do not find in the accompanying rock.

The principal theories, according to Von Herder, may be distributed under four heads:

1. *Congeneration Theories*, which consider the veins as having been formed contemporaneously with the accompanying rock, and not by subsequent filling up. This antiquated view has too much against it to require any special refutation.

2. *Theories of Lateral Secretion.* According to these the contents of veins are to be considered as leachings or deposits of solutions of the accompanying rock. Metallic substances are supposed to have been deposited from salts or other combinations upon the solid walls of the veins by means of galvanic processes. That the component particles of calc spar, gypsum, talc, and of geolitic and silicious minerals, may have been dissolved in water from the accompanying rock, and deposited as such minerals on the walls of the vein by evaporation of the water, is, as above remarked, very probable; but the occurrence of metallic minerals can hardly be explained in this manner. This theory is thus very one-sided.

3. *Theories of Descent.* These were earnestly supported by Werner, who endeavored to accommodate all facts to the prevalent Neptunian hypothesis. He considered the vein mass to have been deposited in previously existing cracks, just as the stratified rocks were deposited from water. Single vein masses have unquestionably been formed in this way, but they are of quite unfrequent occurrence. To this view it may be objected, that older and newer, primary and secondary minerals, may be distinguished in the same vein; that it has not yet been proved that all veins wedge out below, the contrary being capable, in many instances, of complete demonstration; that the same matter ought to have been deposited in other situations than in veins alone, which has not been known to occur. Conversions and metamorphoses have unquestionably been produced in the upper portions of veins, by the penetration of small quantities of water, as shown in the formation of carbonate of lead, sulphate of lead, and phosphate of lead, as well as chlorine combinations of lead, from galena, &c. Nevertheless, this theory, thus restricted, is not accepted by the disciples of Werner.

4. *Theories of Ascent.* These endeavor to prove a filling from below upwards. The ascent may take place in various ways, either by injection, by penetration of the vein mass in a molten condition, by infiltration, by deposit on the walls from ascending mineral waters, and by the sublimation or deposit of solid particles from a gaseous state of aggregation, produced by a diminished temperature. Formations of this character we may see going on now before our eyes, and especially the sublimation in volcanic

operations. It not rarely occurs that cracks which start in lava currents become lined with crystallizations of specular iron, common salt, and sal-ammoniac. The sublimation of galena in stack furnaces, which is deposited in splendid crystals, is a fact of high importance. The infiltration spoken of under this head must, perhaps, be distinguished from lateral secretion; water, indeed, may in great part have leached the accompanying rocks, and have collected at the bottom, there, however, to be heated and driven up. Thus we do not have an immediate lateral secretion, but an ascending infiltration. This has not, indeed, been observed in veins; yet some plausibility is derived from the analogies furnished by the Carlsbad fountains and other springs, which deposit calcareous sinter or hydrated oxyde of iron, as also by the hot springs of Iceland, the Geyser, the Strocker, &c., which deposit silex and chalcedony. These deposits take place not only on the exposed surface, but also on the inner walls of the fountains.

Although some of these theories may be capable of explaining particular phenomena, yet we may not assume that the causes they suggest are the only ones; it is exceedingly probable, that of many agencies, both past and present, which have played and are still playing their part in the bosom of the earth, we are entirely ignorant.

17. *Fossil Organic Remains, their Relation to the Existing Organic World, and their Significance in a Geological Point of View.*

Petrifactions are organisms more or less perfectly preserved, and partly or entirely converted into stone. It must not be understood, however, that an organic substance has really been transformed into an inorganic, but only that as particles of the former have been removed by decomposition or other causes, their places have become filled by mineral matter. Some, however, must be considered as simple transformations of organic matter, as is shown in the conversion of wood into coal.

Petrifactions in general may be considered:

1. In a natural history point of view, by which they are classified and described. Their most natural classification is that which interpolates the different species of animals and plants into the present zoological and botanical series. As many of them are forms entirely foreign to those which now exist on the surface of the earth, such an arrangement is capable of furnishing the most desirable and interesting conclusions with reference to the development of organic life.

To every one who has been at all occupied with a special study of botany or zoology, the fact will be familiar, that among closely related classes, orders, families, and genera, there occur species which it is difficult to refer to one division rather than to another; species which appear to form the actual transition from one such division to the rest. In other cases the reverse is seen, and groups stand out isolated from all others; species even occur which are apparently disconnected with their fellows.

These gaps, which thus exist in our systems, built up from our knowledge of the present living world, are in a great measure filled up by the fresh material derived from the study of past races. It is not necessary to the character of a fossil remain that actual petrifaction shall have taken place, the bones of animals dug up from caves, or found buried in alluvium, being truly fossil, and yet possessing much the same composition with recent bones. To qualify an object for a place among what are technically called organic remains, it is necessary for it to have become extinct at some time before the historical age of the world. In some cases, however, as in certain species of shells and numerous vertebrata, the same species occurs as living, both before and in the present geological era; in this case their ancient remains are still true fossils. The science which thus treats of long extinct individuals, as well as species, is called *Palæontology*.

2. The second point of view from which we look at organic remains is the *geognostical*, inasmuch as they are found in stratified rocks. In these they occur in various forms, sometimes as actual remains, and at others only as casts or impressions of what once existed. The parts of the organism may have vanished, with or without the space vacated having been filled up by mineral matter. Again, certain cavities originally existing in the object may now be penetrated and occupied by stone. The external shell of the animal, when such existed, is sometimes preserved and sometimes not. The penetrations of inorganic matter occur very frequently, and consist principally of lime, clay, and silex. The penetration of silex is exceedingly interesting, inasmuch as it was frequently produced by infusoria. These animalcula, with their silicious skeletons, and in infinite numbers, probably attacked the soft side of animals, and in dying left their skeletons on the spot. This is very conspicuous in some fossil echinidæ, whose calcareous shell incloses a silicious nucleus, which, under the microscope, is found to consist of such organisms. Some parts of organic matters have also experienced alterations, as well by chemical decomposition as by mechanical substitution. An example of such chemical decomposition is found in lignite, which originally consisted of wood. A substitution is often effected by silex; thus we sometimes see entire trunks of trees of it, and not unfrequently one half of a tree or branch replaced by the silex, the other half still continuing to be lignite. This silex, probably, in a dissolved state, permeated the entire tissue, filling up the spaces left by the removal of the organic matter. The pyrites, also, which sometimes lines the cavities of fossils, in all probability, infiltrated the mass in the state of sulphate of iron, and was subsequently converted into the sulphuret. It is well known that decomposing organic matter furnishes powerful means of reduction, by abstracting oxygen, to combine with their own decomposing particles, which are thus converted into various volatile gases. Another mode in which organic bodies occur in the strata of normal rocks, consists in the preservation of some portions and not others. Thus the shells of mollusca are most frequently found without the animals. The organic matter may also have disappeared from these shells, leaving them in a calcined state.

18. *Occurrence of Fossil Remains.*

Strata are far from always presenting organic remains, these being only found in such as have been deposited from water. It is sufficiently evident that they cannot occur in igneous rocks, any indications of their existence in such localities being entirely accidental. This, indeed, is sometimes exhibited where abnormal masses stand in immediate contact with normal, and include them. A feature of this kind is seen in Radauthal in the Hartz, where fragments of sandstone, containing impressions of leaves, are inclosed by euphotide.

Organic remains have been found to occupy a definite relation to strata. Thus some are entirely characteristic of certain formations, groups, or systems, and even of individual strata. Certain species and genera are limited to particular localities, while others are of more general occurrence; they are either mixed up or they lie distributed in a regular manner. Animals and plants most generally occur in different strata, the former in limestone, the latter in clay, although this relation is not exclusively maintained. It not seldom occurs that organic remains, as of shells and corals, compose the principal material of entire beds. This is abundantly illustrated in the Silurian system of North America and Europe.

While by far the greater number of fossil remains are evidently very different from the recent, there sometimes occur instances, especially in the newer strata, of extraordinary similarity. They are, however, in most cases specifically different, and of considerably larger size. The few species which have been found, both fossil and recent, are of very great interest to the geologist. While older petrifactions occur quite universally distributed over the surface of the earth, these are found only in restricted localities, so that from them we are entitled to infer a climatic difference. The same general features of climate must have prevailed all over the earth in the earliest periods of her history, nearly the same mean temperature existing at the poles as at the equator, or else there could not have been this uniform distribution of animal and vegetable life. This is, nevertheless, an assumption which is not well established, the reasons both for and against being numerous. A very cogent reason against it is the occurrence of the elephant and rhinoceros frozen up in the ice of Siberia, which were well prepared to resist the cold that is so eminent in that country. A specimen was found in 1799, with the flesh and hair still perfect, and with remains of the arctic coniferæ in its stomach.

Fossils often occur in localities far distant from the places where allied forms now exist in a living state, as shown in the above-mentioned instance of the European elephas, primigenius, or mammoth. Remains of the lion, tiger, hyena, crocodile, monkey, &c., are found in England, France, and Germany, where even allied families hardly occur. A remarkable (and perhaps still problematical) case is furnished by the occurrence of a petrified *Juglans cinerea* in the Wetterau, the tree being a familiar member of the present flora of North America.

19. *Improvement of Organic Forms with the Increasing Age of the Earth.*

A little attention to the succession of organisms, as presented by fossiliferous strata, will soon convince us of a progressive improvement and perfection of forms. The most imperfect are found in the oldest strata, and the higher they occur in any formation, the higher the degree of their organization. By this, however, it is not meant that plants existed at first alone, and that after they had attained their highest degree of development, then the lowest animals made their appearance, but rather that the development of the animal and vegetable world took place in two parallel series. The oldest plants and animals stand so closely together, that in many cases it puzzles the most skilful palæontologist to decide when any given fossil belongs to one or the other.

Neither must we be understood as affirming that the plants and animals, as they at present occur, are the result of an actual development of the lower forms into the higher, the noblest forest trees proceeding by insensible gradations from the minute cryptogamia, and man from the monad. We simply mean that in successive creations, at successive epochs, the new forms were of more highly organized character than the old. And while the general fact may be as just expressed, there are many special exceptions, numerous instances existing where there appears to have been an actual retrogression. Thus at one time the seas of Europe swarmed with enaliosaurians of immense size and high organization; the Ichthyosaurus and Plesiosaurus devastated the marine regions which they inhabited. Yet all traces of this high order of reptilia have vanished from our existing fauna, unless the far-famed sea serpent be a representative, as has been suggested by some zoologists. The gigantic Dinosaurians, too, have vanished; and of the once extensive order of Crocodilians, only a few imperfect forms remain here and there on the surface of the earth.

The oldest plants were probably those belonging to the land, water plants being found long after; that is, in much more recent strata. The case was different with animals, the oldest having been marine.

In the oldest formations acotyledonal plants come first, and then monocotyledonal; a few dicotyledons next occur, subsequently to present themselves in greater number.

Among animals corals are found first, then radiata and crustacea, and afterwards fishes. Mollusca and radiata then occur more abundantly, and in enormous quantity, and afterwards the most extraordinary and gigantic reptilia. Subsequently we find mammalia, more rarely birds. Human remains occur only in formations of our era, and which are going on at the present time.

20. *Relation of Palæontology to Geology.*

It will have been understood from the preceding remarks that palæontology forms one of the most important branches of geology. It is almost indispensable to the accurate determination of strata groups, since the organic creations of certain periods are found to be much more constant, and more generally distributed than the contemporaneous mineral deposits. As we shall see subsequently, sandstone, lime, clay, and marl substance, alternate with each other in the most varied manner; and it would be a matter of the utmost difficulty, nay, of almost absolute impossibility, to decide without the assistance of organic remains, and upon simple petrographical characters, upon the relative age or the identity of strata in different regions of the world. Modifications in the fauna and flora of a certain period of time may, indeed, occur; but this is only in single cases, and especially in the more recent deposits, where, as already remarked, it is impossible to mistake a difference in the external influences on organization.

21. *Object of Geology.*

The object of geology, in connexion with palæontology, is indeed important, and interesting as important. It seeks to develope the geography of the earth, as it existed at various periods of time, to point out what extent was possessed by the sea, what by the continents, what course was held by rivers and streams, and by what inhabitants peopled. Geology, however, is not merely an interesting subject of study and investigation, it is one of extreme importance to practical life. A rational system of mining is impossible without it, and how necessary is it in an agricultural point of view! To very many sciences and arts it is of most exceeding value.

IV. SPECIAL OREOGRAPHY.

Special Oreography treats of the relations and peculiarities of the solid crust of the earth, and of the order in which the different rock species are grouped. The classification into formations, groups, systems, &c., is based on pure experience alone, since the laws prevailing in regard to the composition of the earth's exterior cannot be developed by hypothesis. This section of geology is naturally subdivided into two parts, one having reference to *normal rocks*, the other to *abnormal*.

NORMAL ROCKS.

Normal rocks are especially characterized by possessing and exhibiting a

definite and regular order of succession, in which we may always distinguish one superimposed or applied stratum or series from another subjacent to it. Normal masses consist partly of isonomic, partly of heteronomic rocks; the former generally prevailing in the older, the latter in the newer formations. A somewhat similar relation exists in the isonomic rocks in which silex or carbonate of lime prevails; the former is generally inferior, the latter superior. In most strata of rocks there is not the least difficulty in determining that they have been deposited from water, especially from sea water; such rocks are called Neptunian. In others, again, this aqueous character is obliterated to a greater or less extent, and for certain reasons we conclude that such have been transformed from their original condition to their present by means of various agencies; such are called metamorphic rocks.

The occurrence of fossil remains is as characteristic of the normal masses as their absence is of the abnormal. They are found in very many of the normal rocks, but following them up from the recent formations to the more ancient, we after a time find that they cease to present themselves. The class of normal deposits falls naturally into three orders, as established by Hausmann: into *bottom series*, *middle series*, and *top series*. Others, as Elie de Beaumont, Sedgewick, Murchison, and others, do not receive this arrangement, not separating the bottom rocks so decidedly from the others, but including them with the transition; the basis of their division would rather be into palæozoic, secondary, and tertiary.

Bottom Series.

The principal character of these rocks consists in their forming the basis upon or against which all the other normal masses rest. They occur as well at great depths as at considerable elevations, either free or covered by other rocks. Their purely chemical formation is unmistakable, for the species composing them are all of crystalline texture; and this character is so universal as to enable us confidently to assert the absence of the bottom series where conglomerates exist. Silicic acid is one of the most predominating ingredients, both in the form of a silicate and of silex. It is combined generally with the oxydes of aluminium, potassium, sodium, calcium, magnesium, iron, and manganese, with them forming micaceous and feldspathic minerals. That the rocks of this division are metamorphic is exceedingly probable; at least we know this to be the case with respect to crystalline limestone, or marble, this occurring in fact as a subordinate mass between the crystalline shales. It must be remembered that the bottom series were most exposed to the influence of the abnormal masses, from resting immediately on them. The frequent eruptions from the heated nucleus of the earth, formerly of much greater extent than at present, appear to have attacked these strata first, filled them with cracks and fissures, and metamorphosed them by the influence of a high temperature. It is also exceedingly possible that the ascending central heat of the earth,

at one time so much more intense at the surface than subsequently, produced great changes in the fine, loose, badly conducting matter deposited from the water. The stratification of bottom rock masses is very decided, and in many cases is effected by micaceous substances. The strata generally stand at considerable angles to the horizon, sometimes nearly perpendicular, and not seldom entirely inverted: fan-shaped and arched strata in every variety also occur. The principal species of rock are gneiss, mica schist or flagstone, chlorite schist, and talc schist. These form the principal mass, and stand more or less in connexion; while the subordinate masses to which steatite, dolomite, and marble belong, are confined to single beds and limited districts. The bottom rock is very rich in mineral substances, as various silicates, metallic oxydes, ores, metals, and metalloids. Of metallic oxydes magnetic iron ore is the most abundant; the ores are generally mixed with arsenic and sulphur; the native metals are gold, silver, and copper; the metalloids principally carbon in the form of graphite and sulphur; this latter of rare occurrence. This rock never contains fossil remains. The occurrence of abnormal masses in it is of especial importance; between these and the mass of the bottom rocks it is often difficult to draw a line of distinction.

A definite order of succession is frequently exhibited among the members of the bottom series, which, however, is not constant. The gneiss is generally the lowest. It occurs in all modifications, in one place as common, in another as granitic; and again, but more rarely, as hornblende or talc gneiss. Its stratification is more or less evident, sometimes partially or entirely curved, sometimes straight. It sometimes exhibits a wood-like structure, depending on an extension of its components, in which case it splits, not into plates, as is most usual, but into pieces like billets of wood. Naumann, who has minutely investigated this feature in gneiss, calls it linear parallelism. The mica schist or flagstone, which generally overlies the gneiss, resembles it closely in its external character. Next to this come chlorite schist and talc slate, either separately or together. Instead of the chlorite schist we frequently have chlorite rock, this generally exhibiting a coarse stratification. These primary masses sometimes run one into the other, in such a manner as to render it difficult to draw the line of distinction; and although generally succeeding each other in the above-mentioned order, yet not unfrequently they alternate.

Subordinate masses of the bottom series are the following:

Hornblende flag and hornblende schist, which run into each other; their place is next to the mica schist, with which they alternate. This is the manner of their occurrence in the St. Gothard, and in several districts in Sweden. The place of the hornblende schist is sometimes assumed by hornblende rock. The stratification of these subordinate masses is not generally so distinct as that of gneiss; the cleavage is, however, so much the more decided, as is beautifully shown in a quarry of hornblende flag near Ruhla in Thuringia.

Hornblende gneiss occurs more rarely, generally existing near the gneiss, and at times even forms independent masses in it. Weiss-stein (Werner) or

granulite (a finely granular feldspar), occupying a similar relation to gneiss, occurs in a few localities, particularly in the ore mountains of Saxony.

Less important subordinate members are schorl schist, graphite flag, micaceous iron schist, marble, and dolomite flag. Horn-slate occurs only in a few places, and clay shale connects the bottom rocks with the transition. Steatite forms isolated masses, especially in chlorite and talc slate, with which it is closely allied. Marble and dolomite, although subordinate, are yet very important and conspicuous members. They are either feebly distinct or closely connected together, and sometimes form entire mountains. They occur most generally in chlorite and talc slate, more rarely in clay shale. They have no distinct stratification, but a three-fold cleavage.

The minerals composing the rock species occurring in the bottom series are not unfrequently separated, occasionally in fine crystallizations. Thus we find quartz and feldspar in gneiss, mica in gneiss, and mica schist, as also garnet, actinolite, tremolite, graphite, &c.

Ore beds and veins occur here in the greatest profusion. The various associated mineral species are either separate or in combinations of various kinds. Beds are found of metallic oxydes, as of magnetic and specular iron ore, in Norway, Sweden, Siberia, North America, Brazil, and other places. There are also ores, as of iron and copper pyrites, zincblende, galena, mispickel, &c., this being particularly shown in gneiss, mica schist, and chlorite slate.

The veins are auriferous, in company with quartz and iron pyrites (in hornstone and gneiss); silver ores, as brittle silver glance, silver glance, antimonial silver, &c., with iron ores, as brown iron ore, specular iron, micaceous iron, &c.

Veins of galena are generally accompanied by calc spar, brown spar, and quartz; veins of copper ores (consisting of copper pyrites, glance copper, and grey copper), by barytes; veins of cobalt and bismuth, by fluor spar, calc spar, and barytes. Furthermore, veins of antimonial glance and tin ore, with mispickel, molybdena, tungsten, scheelite, occur in connexion with fluor spar, apatite, chlorite, &c. Others, again, are met with, without any metallic minerals, as also some which are filled with abnormal masses.

The bottom series is often of considerable extent, and of various external form, dependent upon the petrographical character of the members; upon the influence of continually destructive forces; upon the more or less compound character of the rocks; upon the stratification; and upon the varying situation above the level of the sea.

Where the bottom series is not considerably elevated above the sea, it forms a hilly or mountainous country (as in Sweden, Finland, and North America), in which the waters have excavated deep channels, widening in places into lakes, as may be seen on a large scale in Finland. These excavations follow either the line of direction of the strata, or that of secondary cleavage. When the sea coast consists of strata of the bottom series, it is generally provided with deep indentations, forming the cliffs seen so conspicuously on the coasts of Sweden and Norway. With a greater elevation of the crystalline shale, its forms become more prominent:

moderately high, dome-shaped hills, alternate with deeply cut valleys, their slopes provided with rough and rugged rocks. When of Alpine height, this rock exhibits heights, sharp combs (horns, needles, teeth), separated by valleys, whose steep sides run up from immeasurable depths. Transverse valleys, contracting and widening, with terraced slopes, over which dash foaming torrents, divide the heaven-aspiring rocks.

The ground resulting from the weathering of the bottom series varies much with the subjacent stone. That produced from feldspathic rocks, as gneiss, whitestone, &c., furnishes a mixed, loose, and exceedingly fertile soil, highly favorable to vegetation, on account of its richness in potash, soda, and alumina. The case is different with the non-feldspathic crystalline schist: these generally decompose into a sterile, poor soil. Marble and dolomite separate mutually into a [illegible] and dolomitic sand, this division being facilitated by a proportion of iron pyrites. The swelling of the latter produced by oxydation, crumbles down the rock with irresistible force.

The bottom series, which not unfrequently form entire mountains and mountain chains, occur in Norway, Sweden, Finland, Great Britain, in the Hartz and Thuringia (only in traces), in the Saxony Erzgebirge, in Bohemia and Moravia, in the Spessart, the Odenwald, the Black Forest, and on the Italian side of the Alps; also, in the Cevennes, in Galicia and Portugal, in middle and western France, in the Pyrenees, the Sierra Nevada, the Northern and Southern Apennines, Hungary, Siebenbürgen, and the neighboring region of the Danube. In other countries than Europe, it is found in Asia, from the Ural to Siberia: in the Himalayas and the neighboring mountains. In New Holland and North America, it occurs in great extent.

Middle Series.

The essential geognostical character of the middle series consists in its resting on the bottom, and in being covered by the top series. The species composing this series are unquestionably Neptunian, being partly chemical formations of water, and partly mechanical deposits; they thus exhibit both isonomic and heteronomic formations, which, in the vicinity of abnormal masses, have experienced certain modifications. The occurrence of carbonate of lime is one of the principal characteristics of the middle series, here presenting its highest degree of development. It is either compact limestone or crystalline marble, and of various degrees of purity. It generally contains admixtures of carbonate of magnesia, or of alumina, in greater or less quantity. The presence of the former converted it into dolomite, of the latter into marl; both together, into magnesian marl. Next in quantity and extent to limestone, comes silex.

Various salts, as gypsum, anhydrite, rock salt, carbonate of iron, &c., are very abundant; carbon, also, is extensively distributed, and by its combinations with oxygen and hydrogen, sufficiently proclaims its organic origin. The occurrence of veins, especially of native metals, is less frequent

than in the bottom series, decreasing with the distance from the latter. Conglomerates and sandstone are met with more abundantly, and alternate with masses of marl, with occasional beds of clay interposed. The strata are generally more extended than in the bottom series, and saddle and trough formations are of more frequent occurrence.

The middle series, although often existing at considerable heights, more generally occupies the less elevated parts of mountain masses. It is deposited, either conformably or non-conformably, on the bottom series, in the former case passing as gradually into the bottom rocks, as it is sharply distinct in the latter.

Organic remains are found in most members, sometimes existing in such quantity as to have furnished the principal matter of the strata. The greater number of these remains belong to extinct creations, the more recent strata alone exhibiting forms bearing an affinity to the present. The middle series is divisible into a *primary*, *secondary*, and *tertiary*.

Primary Middle, or Transition Rocks.

A portion of the palæozoic group of Elie de Beaumont belongs to this division of our subject. The primary middle separates the bottom series from the floetz, in external appearance having much in common with the former. The more recent transition strata incline still more in character to the floetz. The strata are more oblique in the vicinity of the bottom series than at a greater distance. Conglomerates, with a cement frequently crystalline, alternate with purely chemical products of an imperfectly crystalline or amorphous character. Limestone occurs more conspicuously in the newer beds. This is sometimes in the form of marble and dolomite; found more abundantly, however, in that of limestone and compact magnesian limestone. Carbon is found partly pure, as in anthracite and graphite, and partly combined with oxygen and hydrogen as coal. Metallic minerals occur, but in less abundance, than in the bottom series: of metals there are gold, silver, copper, and mercury;—of metalloids, arsenic and antimony;—of ores, galena, sulphuret of iron, magnetic pyrites, copper pyrites, zincblende, red silver ore, glance antimony, grey copper, and cinnabar;—of oxydes, specular, red, brown, and magnetic, iron ores;—of metallic salts, principally sphærosidrite, and electric calamine. These occur in beds and nests, as also in veins, the latter sometimes of great extent. The number of fossil remains increases with the distance from the bottom series; plants make their appearance in the more recent transition strata, as in the anthracite coal measures, which bear the impress of a damp insular flora. Decided cotyledons are not yet found; acotyledons, however, exist in abundance. Two formations may be distinguished: the transition slate, and the carboniferous.

Transition-slate Formation. It is this formation which most nearly approximates to the bottom series, so as to exhibit an insensible gradation

into it, when their mutual stratification is conformable. The clay slate is here quite characteristic, and presents itself in the most varied modifications, among which chlorite and talcose occur in particular places. Next to this comes grauwacke, as grauwacke shale, along which are arranged sandstone and quartz rock. Compact limestone and dolomite occur here only in proportion to the floetz. Fossil remains are found only in single beds, and coal is seldom concentrated in large masses. The principal species are :

Clay Slate, as common roof, alum, and calcareous clay slate. Its stratification is very perfect ; sometimes entirely straight, sometimes bent in greater or less curves, and again contorted in every imaginable manner, it occasionally traverses whole mountains. It is almost always found in considerable masses, and frequently alternates with the other members of the transition shale, as with chlorite schist, talc slate, grauwacke and grauwacke slate, hornslate, jasper, silicious shale, and quartz rock. In places where no abnormal masses could operate on it, it occurs as slate clay.

Chlorite and Talc Slate, of a character much as in the bottom series. They are nearly allied to schalstein, into which they pass, as also into chlorite and talc flagstone.

Grauwacke, in all its modifications, as the common, fine, small, coarse, and large grain, as slaty, and as grauwacke slate. Sometimes one modification prevails, sometimes another. The colors vary much ; grey, however, appears to predominate. Oxyde of iron, penetrating the stone in an ochrey form, gives to it a red coloring. A soil is produced by its decomposition which acts more advantageously on vegetation than clay slate.

Silicious Conglomerate. This passes into grauwacke, and is similarly constituted. It is generally colored red by oxyde of iron.

Sandstone, which passes into quartz rock, and when mixed with mica approaches more or less to mica schist. Its decomposition consists in a mechanical division. It is generally clay or quartz sandstone, and of a light color.

Quartz rock. This not seldom passes into the above-mentioned sandstone. Its colors are white, brown, red, and violet ; it imbeds certain rock species of this formation, as silicious shale, clay slate, and some others. It resists weathering very well, on which account it exerts great influence on the form of mountains.

Limestone. This is most generally compact, pure or mixed with silex, of grey or variegated colors, the latter often connected with the presence of corals. Marble sometimes occurs independently, and sometimes connected with compact limestone, into which it passes. It runs into calcareous clay slate and marble flagstone. Nodules of limestone often lie in clay slate, and are frequently ranged in such succession as to form beds by their contact, which, when of great extent and size, form prominent components of mountain masses. Where it alternates with strata of the transition slate, it exhibits a distinct stratification, which is sometimes greatly modified by the presence of mica. Caves abound in it, these being generally lined and ornamented with stalactital and stalagmital matter. Examples are seen in the Baumanns-cave and Biels-cave in the Hartz, the

cave of Montserret, not far from Cordona, in Catalonia (*pl.* 53, *fig.* 3), and the Grotte des Demoiselles near St. Bauzille du Putoir in the French department of Hérault, *fig.* 1. This so-called transition limestone often contains nests of red iron ore, of spathic iron, and the brown iron-stone, as also of calamine in company with galena and copper ores.

Dolomite, both in its true crystalline state and as compact magnesian limestone. It is very conspicuous, but limited to restricted areas. It also contains caves, which, however, are not lined with stalactites, but with rhombohedral crystals. Weathering converts it into a loose sandy earth.

The extent of the transition slate rocks is often very considerable, as also is their occasional elevation above the level of the sea. In the Hartz, this elevation is about 2800 feet, in the Black Forest over 4000, and in the Andes nearly 22,000. Where the strata are rather level, the mountain forms are generally more rounded, while with a more vertical position these are much bolder. Clay-talc and chlorite-schist often form widely extended plateaus: and where they are intersected by long valleys, elongated mountain ridges. The sides of the transverse valleys, as the Selkethal in the Hartz, and the Schwarzathal in Thuringia, are commonly beset with rocks. Granular quartz rock and sandstone not unfrequently form rounded mounds, which project above the grauwacke and slate masses. Limestone, at low levels, presents nothing remarkable in its forms; the contrary is, however, the case when it occurs at greater heights; in narrow valleys it forms precipitous rocks, which are more conspicuous than those of grauwacke and clay slate. The exterior of dolomite is very rough. The Lurleyfels near St. Goarshausen, in the valley of the Rhine, consists of grauwacke and clay slate (*pl.* 53, *fig.* 5).

In England, where the transition slate occurs in great perfection of development, three systems have been distinguished; the *Cambrian*, the *Silurian*, and the *Devonian*. Hausmann, rejecting the first, only admits the two latter, and characterizes them in the following manner:

a. The older or *Silurian System*, containing only crystalline species, or those approximating to the crystalline. Here belong the older clay slate, chlorite-schist, and talc-slate. The clay slate is distinguished from the more recent clay-slates, by the presence of a silicate of alumina (chiastolite or andalusite) occurring in innumerable quantities of individual crystals in some localities. Schulz, however, from recent investigations, doubts the validity of this character. The occurrence of andalusite may be closely connected with the penetration of clay slate by granite. Fossils exist only in small quantity, and are restricted to individual beds.

b. The newer or Devonian system, in which the grauwacke, in connexion with silicious conglomerate and quartz rock, generally of a reddish color, is the most conspicuous member. Limestone occurs in single nodules and in connected masses. This system contains a greater abundance of fossil remains than the preceding, both of plants and animals. Three principal divisions may be established: one containing clay and roofing slate in predominance; the second, quartz rock: and the third, grauwacke, with subordinate masses of limestone. The clay slate is often fissured, a striking example of which occurs on the Lahn (*pl.* 49, *fig.* 8).

The veins occurring in the Silurian and Devonian systems, of most importance, are: the auriferous; the argentiferous, with red silver ore and antimonial silver, accompanied by arsenic and galena; the hydrargyriferous, with native mercury and cinnabar; the cupriferous, with copper oxydes and salts, combined with quartz and barytes; the plumbiferous, with galena; antimoniferous, with quartz; and pyriferous, with spathic iron. These veins, which are sometimes of great extent, occur principally in the grauwacke and clay slate.

Elie de Beaumont classifies the older strata in quite a different manner. He divides them into a Cambrian, a Silurian, and a Devonian system.

a. The Cambrian system (système Cambrique), according to this eminent geologist, is composed of the strata which rest immediately on the abnormal masses, gneiss, &c., included. It derives its name from the Cambrian mountains in Wales, where it has been particularly studied by Sedgewick. No very conspicuous or decided characters distinguish this system from the Silurian; they are, however, deposited nonconformably, and consist of grauwacke, clay slate, and quartz rock. The limestone, of very dark color and brittle fracture, is in inconsiderable amount, and the clay slate is the same which we have already referred to as containing chiastolite. The rocks rarely contain organic remains, and plainly exhibit the effects of an elevated temperature.

b. The Silurian system (lower grauwacke, terrain ardoisier, système Silurien). We owe our knowledge of this system to the elaborate investigations of Murchison. The petrographical character of the rocks coincides with that of the Cambrian system, although the palæontological and stratification conditions are different. They are found in complete development in England, and have been divided by Murchison into many groups. *Pl.* 46, *fig.* 1, presents a section of the Silurian system. Below all the rest lie the strata of the Cambrian system, A, against which lean those of the Silurian. The lowest group forms the Llandeilo formation, *a*, consisting of beds of sandstone (10) and fine granular slaty grauwacke, sometimes containing lime concretions. Against this, and of course at a higher geognostical level, rests the Caradoc formation, *b*, composed of deep red sandstones (7 and 9), penetrated by dirty yellow veins of quartz, alternating with limestone (6 and 8). Then follow the Wenlock strata, *c*, consisting of clay slate (5) as the principal mass, with richly fossiliferous, dark, and partly crystalline limestone (4). The addition of clay-slate substance carries this Wenlock lime gradually into clay slate. The boundary of this system is formed by the Ludlow formation, *d*. The lowest bed, consisting of clay slate (3), rests immediately on the Wenlock lime; upon this lies a subcrystalline clayey lime (2), called Aymestry limestone by Murchison, and, with the micaceous lime and clay sandstone containing an abundance of ichthyolites, closing the series.

The thickness of the Llandeilo strata amounts to 1200 feet; of the Caradoc, to 2500; of the Wenlock, to 1000 (1800?); and of the Ludlow, to 1500 (2000?). The entire thickness of the Silurian system in England thus amounts to 6200 feet (7500?).

The strata of the Silurian system, in Brittany, exhibit a peculiar character: they are bent in an undulating manner, so that the land consists of small flat hills, whose heights are formed by sandstone, and the valleys by slate. A section of the country between Rennes and Nantes (*pl.* 46, *fig.* 3) will make this sufficiently evident. The undulating layers, *a*, consist of the sandstones; the slates, *b*, occupying the troughs of the valleys. Each wave appears to have been produced by the action of the granite, *d*, in proof of which may be mentioned the metamorphism experienced by the slates lying nearest to it. Many members, occurring in England, in the Silurian system, are entirely wanting in Brittany, such as the Llandeilo flags and the Ludlow rocks. Upon the Cambrian system, A (*pl.* 46, *fig.* 2), there rests immediately a coarse silicious conglomerate, of a red color (1), which, from the accurate investigations of May, appears to belong to the Caradoc rocks, with the incumbent greenish quartz sandstone strata (2), the non-fossiliferous limestones (3), and the fossiliferous quartz sandstones. The strata of a bituminous limestone (5), which alternates with black clay slate, and is known as Figuelles limestone, correspond to the limestone masses which occur in England in the Wenlock group.

c. The Devonian System (Old Red Sandstone, Terrain anthraxifère, Système Dévonien). This has likewise been ably investigated by Murchison, who distinguishes three principal subdivisions in England. *Fig.* 4 is a section of this system as found in England.

The first division, 1, *the tile-stone*, lies immediately upon the upper strata of the Silurian system. It contains a fine-grained sandstone of decided stratification, so as to admit of being split into fine laminæ, serving the purpose of tiles. It passes gradually into the Ludlow rocks, upon which it immediately rests, and with which it has a similar stratification: it contains very many ichthyolites. The second division forms the *cornstone*, 2, an alternation of variegated marls with sandstones and impure limestones, in which are scattered small concretions resembling grains of corn. The upper division, 3, consists of *quartz sandstone*, alternating with coarse-grained conglomerates and marls, through which pass inconsiderable beds of coal. The Devonian system attains a thickness of 10,000 feet in the southwest of England.

The transition slate rocks are very rich in springs, both mineral and hot. Their distribution is very extended, being found in Sweden, Norway, Great Britain, in the Hartz, in Thuringia, Hesse, Wallachia, and Westphalia: in the Rhine mountains, in the Taunus, West Forest, and in part in the Eifel: in Upper Saxony, Bohemia, Silesia, and in the Black Forest, in the chain of the Alps, in Brittany, and other parts of France; in the Pyrenees, the Apennines, in Turkey, Greece, Siebenbürgen, Poland, Russia, and in Africa, as well as America, both North and South. Their rich development in North America has been ably investigated by the New York geologists. Murchison, in connexion with M. de Verneuil, has published very copious investigations upon these rocks as they occur in Eastern Europe.

The remarkable table mountain at the Cape of Good Hope (*Pl.* 43, *Fig.* 26) consists in great part of this rock. The succession of the strata in the Ardennes is very difficult to determine, their features being much obscured by the numerous contortions and undulations (*pl.* 46, *fig.* 5). By reason of these flexures, many strata are brought several times to light on a section, so that it would be very erroneous to consider them as so many distinct layers. It is continued in the Rhenish transition rocks, as shown in profile of the section just referred to.

The Silurian system is indicated by S; upon this rests the Devonian, D. it has been broken through by the volcanic mass V, and upheaved on both sides. The more recent Floetz is seen resting against the right side, as the carbonate of lime *k*, carboniferous sandstone *ks*, the anthracite *st*, and the Vosges sandstone *Vog*. The Eifel, the Hundsrück, Taunus, and the Rothhaar mountain, are heights which form the continuation of the Ardennes. This may be easily followed on the geognostical map, *Pl.* 46, *fig.* 6. Single portions of the Devonian rest on the Silurian near Kronenburg, which appear to have stood in connexion with that in the West Forest, and near Dusseldorf. Upon the Devonian there rests a narrow strip of the carboniferous, at Arnsberg the carbonate of lime, at Iserlohn the carboniferous sandstone, and at Hattingen and Mühlheim the stone coal, which is also seen at Kaiserslautern. Next follows the Trias, which begins not far from Brilon, passes by a small strip of the Devonian in the vicinity of Marburg and Giessen, and ends to the north of Homburg. It again appears at Bittburg. Single portions of the Vosges sandstone occur at St. Wendel and to the northeast of Birkenfeld. Then follow chalk rocks, which occur in the north at Bochum. Their place is supplied in the south by tertiary masses at Wiesbaden and Mayence, in the west not far from Bonn and Gemünd, upon which rest alluvial masses at Frankfort, Darmstadt, and Düsseldorf. Volcanic masses break through the strata at Andernach and Coblentz, as also in Siebingebürge, and in the West Forest.

The other side of the Ardennes appears to be formed of the Hartz and the Thüringerwald, a geological chart of which is presented in *fig.* 9. The Hartz, whose greater part consists of grauwacke, is broken through in the middle by granite, and by small masses of porphyry, which play a greater part in the Thüringerwald. The transition limestone is not inconsiderable in the Hartz, and constitutes at Grund and Rübeland entire mountains belonging to the Devonian system. In proportion as we recede from the Hartz, the strata become more recent: we pass over the carboniferous, the todtliegende, the zechstein, the variegated sandstones, the muschelkalk, the keuper, the lias, the oolite, the quadersandstone, the chalk, tertiary masses, and diluvium. The same order of succession may also be followed from the Thüringerwald.

Fossils of the Transition Slate Rocks. The fossils of the Silurian and Devonian nearly all belong to forms different from those of the present era. Some of the most characteristic are figured on *pl.* 37, principally after Elie de Beaumont.

Stromatopora concentrica (*fig.* 1) exhibits a corolla with fine furrows distributed concentrically on a spherical surface. *Tragos acetabulum* (*fig.* 2), similar to the last, cup-shaped, with irregular pits. *Syringopora bifurcata* (*fig.* 3), *Catenipora escaroides* (*fig.* 4), *C. labyrinthica* (*pl.* 42. *fig.* 65). The *Syringopora* are distinguished from the *Catenipora* by the position of the tubes in which the polyps lived. In both, these are straight: but while those of the former ramify, and have internal walls, those of the latter are arranged singly one after the other; their extremities forming chain or net-like figures. *Aulopora* is a somewhat similar genus, of which *A. serpens* (*pl.* 37, *fig.* 7) is of most frequent occurrence. The small tubular cavities are combined in a reticulation, by which they are distinguished from the preceding. *Cyathophyllæ* and *Astrææ* are also somewhat similar: while, however, the former grow up separately, and may even ramify, in the latter the individual portions are fused together. *Pl.* 37, *fig.* 5, represents *Cyathophyllum cæspitosum*; *pl.* 42, *fig.* 64, *C. hexagonum*; *pl.* 37, *fig.* 6, *Astræa ananas*; and *pl.* 42, *fig.* 66, *A. porosa*. These corals generally occur in associations forming large blocks; others, again, as the Reteporæ, Gorgonias, and Favosites, are different in this respect. These are free, and consist of imbricated tubes, communicating by pores. Here belong: *Favosites polymorpha* (*pl.* 37, *fig.* 8), *Retepora infundibulum* (*fig* 9), and *Gorgonia assimilis* (*fig.* 10). The first star fishes were not free, like those of the present day, but were supported centrally on a jointed stem. A most interesting relation exists between the structure of the fossil Echinoderms and the embryological character of those of the present day. The succession of extinct and fossil forms is beautifully typified in the changes which the existing species of allied families pass through in their progress from the ovum to the adult. The oldest Echinoderms known in Palæontology, are the Cystideæ, these being at the same time the most imperfect. They appear as spherical, armless bodies covered with plates, with an oral aperture on the upper part, an anal on the side, and fixed to the ground by a jointed stem. Then come the Crinoids, fixed like the last, but provided with jointed arms, whose motions sufficed to introduce food into the central mouth. Next appear the Ophiuras, animals with arms like the Crinoids, and fixed when young to a stem or pedicle, from which they become free when adult. Finally, we have the Asteroids, which immediately after birth possess arms and a free motion. The Cystideæ occur in the transition rocks, but very rarely. Crinoids are more abundant. Of these, the individual fossils, as well as larger portions of the arms and stems, are frequently found and known as encrinital joints or bones. The crowns, however, are more rarely met with, and the cause of the separation of the parts is probably to be ascribed to the rapid decomposition of the integuments and consequent dispersion of the portions, produced by death. *Pl.* 37 represents *Hypanthocrinus decorus*, *fig.* 11, *Cyathocrinus pyriformis*, *fig.* 12, *Dimerocrinus isodactylus*, *fig.* 13, and *Cupressocrinus crassus*, *fig.* 14.

Mollusca are of frequent occurrence in the transition slate. Of course the shells alone are found, the soft parts too readily undergoing decomposition.

The hinged bivalves belong to the Acephala or Conchifera; the single unilocular shells to the Gasteropoda. The chambered shells are referable to the Cephalopoda, or cuttle fish order.

The Acephalous Mollusca have a soft mucous body inclosed by a mantle which secretes on both sides a calcareous shell inclosing the animal. The shells are connected at the back by a hinge, more or less toothed. The hinges exhibit differences sufficient to furnish excellent distinctive characters. The shells are united by muscles, by means of which the animal can shut them at pleasure. The Acephala are divided into Monomyaria and Dimyaria, as the shell has one or two closing muscles.

The Monomyaria occur in but slight development in the transition slate, the Ostraceæ being entirely wanting, while traces of the Pectinidæ are exceedingly rare. The Aviculaceæ are of more decided occurrence; of these *Avicula lineata* (*pl.* 37, *fig.* 15) is the most abundant. The Aviculæ have an oblique shell, with an acute process of the hinge, which carries a small tooth.

The Dimyaria are found in great variety, and are especially represented by the Cardiaceæ. These have thick, equal valves, with irregular cardinal teeth, and strong muscular impressions connected with the more or less spherical external form. *Cardium lyelli* (*pl.* 37, *fig.* 16), *C. pectunculoides* (*fig.* 17), and *C. vilmarense* (*fig.* 18). *Cypricardiæ* belonging to the same family, differ in having oblong inequilateral valves. They have two to three principal cardinal teeth, the preceding genus having four. *Pl.* 37 *fig.* 19^{c}, represents *Cypricardia impressa*. Among Acephala the Brachiopoda are particularly abundant; they here attain their greatest development, decreasing more and more in number and variety in the more recent formations. They are bivalve, but recognisable by the inequality of the two valves, one being much larger than the other. The genus *Pentamerus*, to which belongs *P. knightii* (*pl.* 37, *fig.* 19^{b}, and *pl.* 42, *fig.* 62), has strongly curved beaks, and in the interior five longitudinal chambers, two in one valve and three in the other, formed by projecting longitudinal plates.

The *Strygocephala* have an undulating hinge margin, over which the beak of the larger valve projects. A more or less regular triangular space, the hinge space, is thus formed, which is pierced by a triangular perforation, contracting with age, and becoming at last completely closed. *Pl.* 37, *fig.* 20, represents *Strygocephalus burtini* from before, and *fig.* 21 from the side. Leptæna is an allied form, with the hinge margin straight, the beaks very close, and the cardinal area very small and without perforation; *Leptæna lata* (*sarcinulata*, *pl.* 37, *fig.* 22). The species of the genus Orthis have in general the same structure as Leptæna; they are distinguished by the presence of a perforation in the cardinal area; *Orthis lepis* (*fig.* 23). The Spirifers have a straight or curved hinge margin, cardinal area large, with a large triangular aperture and bent beaks. The species *Spirifer radiatus* (*fig.* 24^{a}) and *S. speciosus* (*fig.* 25), are very characteristic of the transition strata. The very distinct Terebratulæ are found in great abundance in nearly all fossiliferous strata. The beak of the larger valve is provided

with a round aperture, through which passes the attaching ligament; under this lies the triangular cardinal area, bordering beneath on the cardinal margin. The most common species are *Terabratula ferita* (*pl.* 37, *fig.* 26), *T. wilsonii* (*figs.* 27 and 28), *affinis* (*pl.* 42, *fig.* 59), *crispata* (*pl.* 37, *fig.* 29), and *imbricata* (*fig.* 30). In the Devonian System we have *Caceola sandalina* of conical shape, provided with an operculum beneath (*figs.* 31 and 32); also *Producta depressa* (*pl.* 42, *fig.* 58).

The Gasteropoda are readily distinguished from the preceding by their external form. The shells of this family are twisted from left to right (dextral), sometimes, however, in the opposite direction (sinistral), and generally consist of one, rarely of two valves. In them we distinguish an apex and a base, in the latter of which is the orifice through which the animal protrudes itself. The axis around which the spiral cone is wound is called the columella or spindle; this is generally solid; when hollow, the aperture of the space included, is called the umbilicus. Some gasteropods possess an operculum by which the opening can be closed after the retreating animal.

The family of Turbinites is characterized by a turriform, conically wound shell, with the mouth entire and rounded. The columella is curved, and ends in a small open umbilicus. The species of the genus Turbo have mostly beautifully ornamented shells. The most important species is *Turbo squamiferus* (*pl.* 37, *fig.* 33). *Monodonta* is allied to Turbo; in this genus the columella ends at the aperture in a projection or tooth: *Monodonta purpurea* (*fig.* 34). The genus *Natica* also belongs here; its species have the spire depressed, the aperture ovate, with a trenchant right border, a callosity masking the umbilicus: *N. subcostata.* *Pleurotomaria* has a conical spire with oblique oval aperture; *P. defrancei* (*fig.* 35), *P. llovdii* (*fig.* 36). *Euomphalus* possesses an inconsiderable spire, sometimes none at all; the aperture perfect, with angular border; umbilicus smooth: *E. rugosus* (*fig.* 37), *E. discors* (*pl.* 42, *fig.* 57), *E. serpula* (*pl.* 37, *fig.* 38). *Cirrhus* is distinguished from the preceding by the conical elevation of the spire, *C. leonhardii* (*pl.* 37, *fig.* 39); in *Schizostoma* the turns of the spire lie in a plane, *S. radiata* (*fig.* 30). Among the gasteropods, with twisted columella and without umbilicus, belong *Buccinum: B. aculeatum* (*fig.* 41), and *Murchisonia*, differing from the last in the oblique oblong aperture, ending in a short canal, and by the ridge which follows the windings: *M. coronata* (*pl.* 37, *fig.* 42). *Bellerophon* has a shell curved like Nautilus, the last winding entirely concealing all the rest; it is, however, not divided into chambers, neither does it possess a sipho: *Bellerophon bilobatus* (*fig.* 43). Gasteropods also occur without a twisted or curved shell, as in *Conulara: G. gervillei* (*fig.* 44). They are tri- or quadrilateral, and narrow above. The half-closed mouth is placed in the base.

The Cephalopoda stand at the head of the Mollusca in respect to their organization. The head, which is furnished with two well formed eyes, is distinct from the body. The mouth is placed in a depression of the head, and contains two strong jaws bearing a somewhat striking resemblance to the beak of a parrot. It is surrounded by a variable number of long

muscular arms, serving the purposes of prehension, for which they are well calculated by reason of the numerous sucking disks on their inner face: these suckers are sometimes still further armed by formidable hooks. In the intestines there exists a sac filled with an inky fluid, and which in some cases has with its contents been preserved in a fossil state. This fossil sepia or India ink has even been used to delineate the fossil remains with which it was associated. The Sepiæ of the present day rarely have external shells; the animal, however, incloses a solid shelly axis, known in the arts as cuttle fish bone (ossa sepiæ). The analogous parts of somewhat similar fossil forms are frequently met with in fossiliferous strata. Only two of the families into which the Cephalopoda are divided, occur in the transition series: the *Nautilidæ* and *Ammonitidæ*. These have chambered shells, the last chamber of which was inhabited by the animal. The young individual formed only one cell, others being successively added, and the last built being the only one occupied. A membranous tube called the sipho passed through to the last chamber, and was connected as to its function with the rising or sinking of the animal in the water. The position of the sipho, whether passing through the middle of the partitions, along the ventral or along the dorsal, characterizes the subdivisions of the chambered cephalopods.

The aggregation of chambers is sometimes in a straight line, widening above, as in *Orthoceras;* of this genus, *O. attenuatum* (*fig.* 45) and *O. annulatum* (*pl.* 42, *fig.* 63) are of most frequent occurrence in the transition. The partitions are slightly concave, the sipho passing through the middle. *Phragmoceras* has a structure somewhat similar, except in being slightly curved below into a horn shape: *P. ventricosum* (*pl.* 37, *fig.* 46). They only occur in the transition state. *Lituites* is rolled up, yet without any contact of the windings: *L. giganteus* (*fig.* 47).

The Ammonitidæ are distinguished from the Nautilidæ by the more or less undulating or zigzag character of the partitions, whose extremities are very distinct externally. The sipho lies nearer the dorsal side. In the Nautilidæ the partitions are simply curved with the sipho in the middle or nearer the ventral side. Here belongs *Goniatites*, as *G. hoeninghausi* (*pl.* 37, *figs.* 48 and 49), and *G. costulatus* (*fig.* 50 and 51).

The class Crustacea is represented in the oldest fossiliferous strata by a very remarkable form, that of the Trilobites. No adult crustacean of the present day is at all similar to the Trilobites: a very striking resemblance is, however, found in the embryo of some recent species. The body of the animal was divided into three principal portions, a head, a thorax, and tail; these were covered by a thin granular or spinous shell, which has rarely been preserved, casts only of these portions being generally exhibited. The head is occupied by a large shield, with a large eye on each side: these may sometimes be recognised as compound by means of numerous facets. The thorax consists of a central longitudinal ridge, with a furrow on each side, and is divided transversely into jointed rings, the number varying from 5 to 20. The caudal shield is divided into similar rings, the central elevation of the thorax being lost in it. Some genera were able to roll themselves up

like the genus *Oniscus* by means of these rings. Striking forms of trilobites are *Trinucleus granulatus* (*fig.* 52). *Calymene blumenbachii* (*figs.* 53 and 54, and *pl.* 42, *fig.* 60). *Phacops downingiæ* (*pl.* 37, *fig.* 55.) *Brontes flabellifer* (*fig.* 56), and the curiously spinous *Arges armatus* (*fig.* 57) and *Asaphus buchii* (*pl.* 42, *fig.* 61). Trilobites occur in the silurian of North America in great numbers, both of individuals and species. Some of these are distinguished for their enormous size, as *Isoteles maximus*, which has been found in Ohio nearly two feet long and more than one foot wide.

Remains of fossil fishes first occur in the transition slate, and of the most singular and unique character. The characteristic form is that of the Cephalaspides, as *Cephalaspis lyelli* (*pl.* 37 *fig.* 58), and *Pterichthys latus* (*fig.* 59.)

Carboniferous Group (*Système houillier, Terrain houillier*). The most important rock species occurring in the carboniferous are grauwacke, silicious conglomerate, sandstone, quartz rock, and limestone, which, in their petrographical character, are often so similar to those of the transition slates, as to be entirely undistinguishable in hand specimens. There is, however, a great difference in the occurrence of clay masses. Thus while in the preceding formation clay exists as clay slate and burning slate, in the present it is found as slaty clay, thus of much less consistence. The strata are generally much more extended, and form wide troughs and saddles. In some places they have been subject to considerable changes of position, being bent, curved, contorted, &c., in the most complicated manner: in others, again, the greatest regularity is perceivable. The most important metallic salt is the carbonate of iron. Fossils enter in large number, some of them coinciding with those of the transition slate. The carboniferous system is more restricted than that of the preceding, and rarely occupies high levels. In this system three principal groups may be distinguished.

a. Carboniferous or *Mountain Limestone* (Encrinital limestone), with the principal rock species, limestone and dolomite; these occur partly crystalline, partly compact and of a prevailing grey color. The mountain limestone forms large masses as well as subordinate beds. The cleavage is quite decided, and sometimes gives rise to the formation of caves. It is often very bituminous, the bitumen being sometimes concentrated in single places. The caves often contain tertiary deposits imbedding the bones of terrestrial mammalia. Nodulous masses or concretions of hornstone often exist in the strata. Slate clay and sandstone occasionally alternate with the limestone. Veins occur much less conspicuously than in the transition slate: those of galena, in company with fluor spar, barytes, and elalerite, are most frequent. The fossils are generally animal. This group abounds in springs.

b. Millstone Grit (Flötzleerer Sandstein). This contains principally conglomerates and sandstones, of which silicious conglomerates, grauwacke clay, and quartz sandstone of a grey color, are the most abundant. They are accompanied by a finely laminated, very bituminous limestone, clay-roofing-, alum- and burning slate, as also by silicious shale, jasper, and

subordinate beds of bituminous and anthracite coal. Argillaceous sphærosiderite is found in considerable quantity.

c. The Coal Formation proper. This is of great importance, as containing the true coal measures. Stone coal is indeed a subordinate, but yet a very prominent member. The principal mass is formed by conglomerates and carboniferous sandstones: of the former granitic and silicious conglomerates are the most important; of the latter, clay, marl, and quartz sandstones. Accompanying and subordinate masses are: limestone, marl, loam, marl clay, and potter's clay, which are generally very bituminous, as also a grey slate clay, bituminous shale, drawing slate, and various modifications of coal. The thickness of this group varies considerably, rarely however exceeding about 900 feet. The strata are rather horizontal than otherwise, although there are sometimes very great irregularities of position. The coarser conglomerates generally occupy the lower levels; the finer, the higher. A similar relation occurs between anthracite and bituminous coal; the former occupying the lower, and the latter the higher measures. The coal beds are generally only a few feet thick. The thickest known are those of Fimini (33 to 40 feet), and those of Dudley in England (33 feet).

The cleavages of the coal are generally distinct, and cut each other at right angles. The roof and floor of the bed generally consist of clay shale. Nodular masses of arsenical and iron pyrites, argillaceous carbonate of iron or sphærosiderite, galena, zincblende, are sometimes collected in larger or smaller quantity. The occurrence of native mercury, amalgam, cinnabar, and horn quicksilver in coal measures, is exceedingly remarkable: these bodies concentrate in nests and are thus found in loam. Organic remains are met with in extraordinary abundance, being principally confined, however, to plants: animal forms are much rarer (mostly fresh water mollusca): fishes are nearly wanting. Such remains are generally in excellent preservation, especially when they lie in the very fine shales. In these the finest nervures of the leaves are sometimes retained. Coal itself is entirely composed of transformed vegetable matter, as is abundantly shown by microscopic and other investigations. Springs abound in the carboniferous system, particularly those containing iron and salts of sulphuric acid. The true stone coal group is very extensively distributed: it occurs of great extent in Great Britain, Belgium, in the vicinity of Aix la Chapelle and Eschweiler, about Saarbrück and in the trans-Rhenish Palatinate; on the borders of the Hartz in less quantity, more abundantly in Thuringia; also in Saxony, Moravia, and Silesia; in extensive districts in France, some portions of Spain, Portugal, North America, China, Japan, and New Holland.

One of the most considerable coal basins is that of the Palatinate, which is about forty-four miles long, and from seven to thirteen miles broad. It rests nonconformably upon the transition slate rocks, while it is covered by Vosges sandstone and alluvium. *Pl.* 46, *fig.* 8, is a section of this field: K indicates the coal strata, V the Vosges sandstone, and A the alluvium. This field is often broken through by various porphyries, causing a

disturbance of the strata. The amount of coal is very small in proportion to the extent of the basin. It is only in two places, to the north on the Glan and to the south near Saarbrück, that the yield repays the expense of mining. The most important bed is about thirteen feet thick. The English coal formation is more extended, and by the abundance of coal exercises a great influence upon the production of iron. Much of the English iron is derived from sphærosiderite (carbonate of iron), which occurs in large quantities in the carboniferous system, and even in the coal measures themselves, so that the same mine may furnish both ore and fuel. It is to this, above all, that the cheapness of the English iron is owing. *Pl.* 46, *fig.* 7, represents the succession of strata in the English coal formation. It there rests immediately on the Devonian, *a*, against which leans the mountain limestone, *b*; next come the strata of the millstone grit, *c*, which are covered by the lower coal beds, *d*, containing a large amount of iron-stone; next by the main coal, *e*, and the upper coal, *f*, combined with the fresh water limestone. The latter concludes the series, which is succeeded immediately by members of the Permian and new red sandstone.

No country possesses a larger amount of coal than North America, and in none is it found more extensively distributed. It occurs in Nova Scotia, New Brunswick, Massachusetts, Connecticut, Rhode Island, Pennsylvania on both sides of the Alleghanies, Virginia, Maryland, Ohio, and several others of the Western States. Among the most remarkable of these localities are the anthracite beds of eastern Pennsylvania. They are not constituted of the mineralogical species anthracite, but of a variety of common coal containing very little bitumen, and burning with little smoke and flame. This variety occurs in three basins: the Wyoming, the Schuylkill, and the Lehigh. The former is nearly seventy miles long and about five broad, occupying part of the valley of the Susquehanna river.

Fossils of the Carboniferous Period. As already mentioned, vegetable remains are most conspicuous in the coal strata, particularly the vascular cryptogamia, such as Equisetaceæ, Filices, and Lycopodiaceæ, of sizes far exceeding those attained by modern members of the same families. Among the Equisetaceæ belong the *Calamites*, with straight cylindrical branches and high jointed stems. They are striated longitudinally, some with a sheath going round the stem, as in the common Equisetum or horsetail, and others without it. The largest known remains must have belonged to individuals more than a foot in diameter. Such, for example, is *Calamites approximatus*. These gigantic forms sufficiently indicate that certain agencies were at work in the earlier periods of the earth's history, which favored the development of vegetation to an enormous degree.

The different parts of many species of Filicoid plants, as ferns, &c., occur in great quantity: entire stems and leaves of arborescent ferns are found, and it is probable that the great mass of coal has been produced by accumulations of such ferns. Ferns have cylindrical stems, inclosed by circlets of leaves. When these fall off they leave scars behind them, of a lenticular shape, and higher than broad; when the leaves are extended

transversely they never embrace the stem as in monocotyledons. The woody vessels which pass from the stem into the petioles, form regular and characteristic figures. The leaf scars are in parallel longitudinal rows. The stem supports a crown of simply or doubly pinnate leaves. The only possible means which we have at our command for classifying fossil ferns consists in the arrangement of the nervures.

Sphenopteris has bi- or tri-pinnate leaves, with leaflets distinct, deeply lobed, and the nervures radiating nearly from the base. *S. Schlotheimii* (*pl.* 37, *fig.* 60) is especially abundant in the Saarbrück coal beds.

The bipinnate fronds of *Odontopteris* have thin leaflets, adherent by their entire base, which is never contracted, nervatures simple or dichotomous, all equal, proceeding from the rachis; central nervure indistinct: *O. minor* (*pl.* 37, *fig.* 61).

The coal strata are filled with vast quantities of gigantic stems of ferns; they have been found over 40 feet long and a foot in diameter. Their leaf scars are in parallel longitudinal rows, but are in much larger quantity than others in allied forms. Their thin carbonized bark readily falls off, exhibiting the casts of the scars. These are known as *Sigillaria*, of which a stem is figured in *fig.* 62; *fig.* 63 is a piece of the same with the bark removed; *fig.* 64, an enlarged view of the leaf scars both above and below, or within and without the bark.

Stems of Lycopodiaceæ are also found, hardly yielding in dimensions to those of Sigillaria. Thus we have *Lepidodendron* distinguished from the last by the spiral arrangement of the rhomboidal leaf scars. An entire stem of *L. elegans* (*fig.* 65) has been brought to light in the Bohemian coal mines: *fig.* 66 exhibits the arrangement of the leaves: *fig.* 67, the scars themselves.

The coal formation, as far as known, is destitute of true dicotyledons; doubtful forms, however, occur, which may or may not be such, as *Sphenophyllum annulatum* (*fig.* 68), and *Annularia fertilis* (*fig.* 69).

The general character of the invertebrate fauna coincides with that of the transition; nearly the same families and genera occur, although the species are mostly specifically distinct.

In the lower group of the carboniferous system, the mountain limestone, entire strata are filled with crinoidal joints, belonging principally to *Rhodocrinites verus* (*fig.* 70, *a*, *b*), and to *Cupressocrinus crassus* (*fig.* 71, *a*, *b*). Here and there are found pelvic fragments of *Platycrinus lævis* (*pl.* 42, *fig.* 41), *Actinocrinus triginta-digitalis* (*fig.* 42), and a form nearly allied to the crinoidea, *Pentremites ellipticus* (*fig.* 43). These strata have consequently received the name of encrinital or entrochital limestone. The principal mollusca are *Pleurorhynchus minor* (*pl.* 42, *fig.* 44), *Spirifer striata* (*fig.* 46), *Producta punctata* (*fig.* 47), *Terebratula acuminata* (*fig.* 56), *Bellerophon bisulcus* (*fig.* 50), a *Pleurotomaria* (*fig.* 51), *Euomphalus pentangulatus* (*fig.* 52): of Cephalopoda, *Orthocera breynii* (*fig.* 45), *Ammonites listeri* (*fig.* 48), *Ammonites striatus* (*fig.* 49); of corals, *Syringopora geniculata* (*fig.* 53), and *Favosites capillaris* (*fig.* 54); of trilobites, *Asaphus gemmuliferus* (*fig.* 55).

The vertebrate sub-kingdom is represented by a few remains of fishes, principally teeth, belonging to the Hybodontes. *Pl.* 37, *fig.* 72, represents a tooth of *Cladodus marginatus*.

Various hypotheses have been suggested as to the origin of the coal beds. Some of these suppose an accumulation of drift-wood, and others that the vegetation was produced in the spot where the coal is now found.

The latter assumption appears the more probable of the two, demanding, however, a greater length of time, although not so great as would perhaps be required at the present day. The most convincing proof of the indigenous origin of at least many of the coal beds is found in the fact, that tree-stems are found standing upright in sandstone strata of the carboniferous, at right angles to the stratification, and partly carbonized, partly pyritized. In some places it may be clearly seen that the roots of such stems were implanted in beds of slate clay. A curious instance of this is found in a coal mine near Treuil, not far from St. Etienne, as shown in *pl.* 52, *fig.* 7. The upper beds are of sandstone, in which are contained the erect stems; beneath this is a deposit of argillaceous iron-stone, resting on a bed of shale; the whole lies above the coal bed. Similar phenomena are found in various other coal mines.

Secondary Middle Series.

This follows immediately after the carboniferous system, and is covered by the tertiary middle. Crystalline masses are here in but slight amount, and stand in decided connexion with abnormal formations. Clay, marl, lime, and sandstone masses here attain a high degree of development. They frequently alternate with each other, and occur in all modifications. Single coarse conglomerates present themselves only in restricted localities. The clay, lime, and marl masses are generally colored by carbonaceous matter, although sometimes they are of a pure white. Coal is of rare occurrence, as also is that of metallic minerals. Veins are sparingly distributed, and hardly worth following up; karstenite or anhydrite, gypsum, and rock salt, are of more importance.

The secondary middle series or Floetz is very rich in fossil remains, these occurring both in vast numbers of individuals and of species. Forms of the animal kingdom exhibit a great preponderance over the vegetable. The former are principally aquatic, as mollusca, fishes, and reptiles, the latter of colossal size and wonderful forms. Among the few plants dicotyledons are of decided occurrence.

The Floetz generally occupies low levels, with strata more or less horizontal, and is divided into four formations. It has the most extended distribution of all the members of the middle series.

Copper-slate formation (*Permian System. Penæian System. Magnesian Limestone*). This, according to Elie de Beaumont, likewise belongs to the palæozoic rocks, and embraces the red sandstone, the zechstein, and the rauhkalk. The principal rock species consist of various conglomerates and

sandstones, the former predominating, and generally of red color; also marl, limestone, and dolomite, mostly bituminous; gypsum and karstenite, all of which, although not principal masses, are yet very conspicuous. Carbonate of iron and oxyde of iron are subordinates. Veins are much less in number than in the carboniferous system; a few inconsiderable beds of copper, cobalt nickel, bismuth, and molybdenum ores also occur. This first formation possesses the fewest fossil remains of all the floetz. The diminutive Flora approximates to that of the carboniferous, but differs in the decided presence of dicotyledons. Orthoceratites and trilobites here find their limit; fishes of the ganoid type become more abundant, as also reptiles. This copper slate formation is, on the whole, not abundant, and only in few cases takes a high stand among rocks. It is divisible into two groups; an under, the red sandstone, and an upper, the old floetz limestone.

a. Red Sandstone (Todtliegende). This consists of coarse and fine conglomerates and sandstones of red or reddish-brown color. White or grey sandstones sometimes occur, which then occupy the upper regions of the group. Upon this distinction of color rests the distinction made by the German miners into red, grey, and white sandstone (liegende) which are found to exist in this order.

The conglomerates met with are granitic, argillaceo-ferruginous, silicious, porphyritic conglomerates, and grauwacke. The sandstones: iron-clay, clay, and marl sandstones. An accompanying deposit is formed by red or grey limestone, which not rarely alternates with iron clay.

The conglomerates and sandstones in general present nothing remarkable in their exterior; where deep valleys or ravines intersect the mountain ridges, they produce the most singular rock forms.

The stratification is generally very decided and of great extent in the coarse conglomerates. The cleavage, not very regular, often produces a columnar structure. The situation of the strata is generally horizontal, although sometimes inclined, especially in the vicinity of abnormal masses.

The grey sandstone is noticeable for sometimes containing ores of copper; these are the copper sand ores mined on the west side of the Ural. Fossils are rare. and limited to a few dicotyledonous trees, which occur in the form of silicified wood, whole trunks being sometimes found.

The soil arising from the red sandstones of this group is reddish-brown, ferruginous clayey, and very fertile. This property is sometimes increased by the abundance of springs.

The new red sandstone in the Hartz (*pl.* 46, *fig.* 9) lies immediately on the strata of the Devonian system, and is covered by the Zechstein. It occurs in greater masses in Scotland, in England, in Thuringia, near Richelsdorf in the electorate of Hesse, in the Wetterau, the Spessart, the trans-rhenish Palatinate, the Black Forest, in Saxony, the Tyrol, the Vosges, in Russia, in the Caucasus, and in North and South America.

b. Old Floetz Limestone. The principal rock species are bituminous marl shale, compact limestone, magnesian limestone, dolomite, and fœtid

limestone. Accompanying species are clay masses, gypsum, karstenite, and rock salt. Where the group is complete, two subdivisions may be distinguished.

The lower division is strikingly characterized by the copper slate, a bituminous marl slate impregnated with copper ores. The proportion of copper is generally small, from one to four per cent. The ores are finely disseminated, rarely collected in mass; they consist of copper pyrites, glance copper, grey copper, iron pyrites, zincblende, arsenical cobalt, and molybdenum glance. From the decomposition of these minerals, various metallic salts, as verdigris and mountain blue, are produced. The strata of copper slate are not generally thick; from one to two, rarely three feet. The thinness of the strata renders it a very laborious matter to mine the copper, the workmen being obliged to lie upon the side or back while extracting the ores. Fossil remains, especially of fishes, abound, owing perhaps to the fact that the great proportion of bitumen has facilitated preservation.

Upon this copper slate rests a fœtid marl, intermediate between copper slate and zechstein. The thickness of the bed varies from four to eight feet. Next comes the zechstein, a bituminous, marly, compact limestone, of brittle fracture, containing clay concretions and drusy cavities. It includes subordinate masses of gypsum, lithomarge, and copper ores, the latter accompanied by the usual salts of copper. The stratification of the zechstein is very distinct, and the rock is traversed by a doubly-rectangular cleavage.

The upper division is exceedingly complicated, and thus difficult of recognition, especially as the petrographical character of the rock species is subject to many modifications, and varies in different localities. For this reason there are many equivalents or representatives. The principal species occur in the following manner:

First, rauhkalk (rough limestone), which, when in normal position, rests on the zechstein. It derives this well-deserved name from the roughness of its exterior. Its rocks are generally full of cavities, and, in some places, contain large caves. Such are the Liebensteiner in Thuringia, the Schwartzfelder and the Steinkirche on the southern border of the Hartz. The rough limestone is sometimes represented by fœtid and magnesian limestones, which are apt to incline to magnesian and fœtid marls; the drusy cavities are sometimes clothed with rhombohedrons of magnesian spar. The colors vary from grey to white, and its cleavage is not regular. In the caves occurring in this rock tertiary deposits are found, containing bones cemented by stalagmite. Fossil remains are limited to single beds.

Next to the rough limestone comes the asche, an earthy fœtid marl of ash-grey color, much darker when wet than dry, and non-fossiliferous.

Then comes the fœtid limestone, which is extensively distributed in the compact form, and is found in thick beds; the shelly, oolitic, spathic, and breccious varieties are restricted to small districts. Zechstein and fœtid limestone are closely allied, especially when the latter is in large masses. The bitumen which is diffused in fœtid limestone is often concentrated in

cavities as asphaltum. It contains few fossils; the forms are principally molluscan.

These principal features of the upper division of the copper slate are generally accompanied by loam exhibiting concretionary masses and traversed by fibrous gypsum, spathic and brown iron-stone, gypsum and karstenite, and rock salt. The gypsum and karstenite are of great purity, and stand in such connexion as to permit the assumption that the one has arisen from the other. Their chemical composition teaches us that karstenite needs only to acquire a certain quantity of water to become gypsum. This explains the fact that pieces of karstenite are inclosed by a crust of gypsum, having absorbed enough water from the atmosphere for the purpose. In mining gypsum we frequently come to a nucleus of karstenite. A considerable increase of volume takes place in this combination with water, and thus by its irresistible expansive action shatters entire mountains. On this account gypseous masses, when of large extent, have a greatly riven aspect. The rough jagged surface is quite characteristic of gypsum, this being produced by the dissolving action of water (one part being soluble in four hundred of water) upon the softer parts of the rock. The compact portions remain behind and cause the roughness. The fissures which arise by the increase in volume of the karstenite, collect large quantities of water, which also exerts its destructive influence on the inclosing rock. Cavernous excavations are thus gradually formed, which may increase so much in time as that the incumbent covering of gypsum, not finding sufficient support, may fall in, causing sink-holes, which are sometimes filled with a saline water. This upper group of the copper slate formation often contains powerful springs, and is extensively diffused in England, in the Hartz, in Thuringia and Saxony, in North America, and various other places.

Among the geological equivalents may be enumerated the so called Frankenbergen formation, where limestone, slate clay, loam, sandstone, &c., rest on the transition slate and contain peculiar vegetable remains, presenting a distant resemblance to ears of grain, for which they were long mistaken. The copper sand ore formation of the west side of the Ural, constitutes another equivalent.

Fossils of the Copper Slate Formation. The fossils of this formation are rare and not well known. The vegetable remains are composed of a few Fucoids, Lycopodiaceæ, stems of not well determined monocotyledons and dicotyledons, Coniferæ: *Cupressites ulmanni* (the Frankenbergen grain ears), &c.; the animals of a few corals, as *Escharites retiformis;* Radiata, as *Encrinites ramosus;* shells, as *Productus aculeatus* (*pl.* 38, *fig.* 1), *Delthyris alata*, and species of *Mytilus*. The Vertebrata consist of fishes and reptiles; trilobites are entirely wanting, and are apparently replaced by crustacea of a Limuliform character. Remains of fishes are numerous, and teeth of *Acrodus larva* (*pl.* 38, *fig.* 2), are characteristic of the zechstein. Reptiles first occur in the copper slate. The single genus known as belonging to this period, is found in the Mansfield copper slate, where its bones occur with fish remains. It is the *Protero saurus*, characterized by its long thin cylindrical teeth implanted in

separate sockets. It forms the transition from the Lacertidæ to the crocodiles.

Pl. 46, *fig.* 10, exhibits an ideal section of the copper slate formation. Immediately on the carboniferous sandstone (*a*), lies the red sandstone (1). against which rests the white red sandstone (2). Then come copper slate (3), zechstein (4), a dolomitic rock (5), asche (6), old floetz gypsum with fœtid limestone (7), and marl beds (8). The whole is covered by the variegated sandstone (*b*).

Rock Salt Formation (*Trias. Terrain salifère. Group triasique*). The rock salt formation marks the commencement of the secondary formation of Elie de Beaumont, and immediately follows the copper slate. The principal rock species are sandstones, limestones, and marls, so arranged that the sandstones occupy the upper and lower portions, including the limestones in the middle, both species being combined by marly forms. Gypsum, karstenite, and rock salt are subordinate members, the latter of which, from its extensive distribution and intrinsic importance, has given name to the formation. Rock salt is generally accompanied by gypsum and karstenite.

The only metallic minerals of importance are galena, electric calamine, and hydrated oxyde of iron. Fossils occur in immense accumulations of individuals, although genera are few: they characterize the single groups and series of beds so perfectly, that no other formation can be compared to the rock salt in this respect: organic remains are, therefore, of especial importance for this formation. Three groups of the rock salt may be distinguished, sufficiently entitled to separation.

a. Variegated Sandstone Group. This is formed by sandstones of mostly red or reddish brown color, accompanied by clay and marl masses. Subordinate masses of the variegated sandstone are: quartz rock, clay quartz, limestone, sometimes oolite, gypsum, karstenite, and rock salt. Among the fossils are vegetable remains of a terrestrial character. This group separates into three subdivisions; the first of which, the Vosges sandstone, is of rarest occurrence.

The Vosges sandstone is sometimes argillaceous, sometimes quartzose, sometimes hard, sometimes soft, either fine or coarse grained, and in single cases inclined more or less to quartz rock. The color is generally red, and the beds sometimes exhibit a thickness of 1000 to 1200 feet. It is mostly distinctly laminated, lying more or less horizontally, and free from subordinate beds and from fossils. It occupies the highest part of the Vosges and of the Schwarzwald.

The middle division, that of the variegated sandstone, does not exhibit this uniformity; the sandstones are sometimes argillaceous, sometimes marly, and of different degrees of hardness, with the most diversified coloration; red predominates. Mica, chlorite, and talc, not seldom lie parallel to the planes of cleavage, as also dendrites of black oxyde of manganese. Calcareous and brown spar are often found crystallized in drusy cavities, these being not seldom found with a red barytes. The stratification is very complete, sometimes finely laminated, this being

produced by mica, chlorite, or talc ; it is also at times very thick, with double rectangular secondary cleavage, which, when in large beds, causes a tendency to a columnar structure. Quartz sandstone, whose strata are sometimes divided into cubes by the secondary cleavage, is limited to single layers.

Fossils occur only in particular beds, and are principally constituted by plants, bearing most resemblance to the coniferæ of the torrid zone. Thus we have *Albertia*, with oval truncate leaves, inclosing the branch in horizontal series : *A. elliptica* (*pl.* 38, *fig.* 3[a]). *Voltzia* comes very near to the *Araucarieæ*, and constituted the greater portion of the coniferous vegetation of the variegated sandstone period. Their leaves are needle-shaped and of different forms, so that on the same branch we may see short scale-like leaves alternating with long needles. The cones are covered with woody flaps, which stand at a considerable distance apart. *Voltzia heterophylla* is generally found in the form represented in *pl.* 38, *fig.* 3[b], more rarely in a combination of fruit-terminal and middle branches, as in *fig.* 4. *Æthophyllum speciosum* (*fig.* 5) is another allied form.

The upper division of the variegated sandstone, or that of the red marl, contains clays, marls, and sandstones, as the chief masses. Subordinated are quartz, granular and brittle quartz rock, this often covered with pseudomorphous crystals from rock salt; also limestone, oolite, gypsum, karstenite, rock salt, and celestine. The stratification is decided. The marls and clays, among which slate clay, clay marl, and marl clay belong, are of a reddish-brown color. Fossils occur but seldom.

Prominent mountain forms do not appear in the group of variegated sandstones ; they form uniform ridges with undulating outline. The valleys generally run parallel to the secondary cleavages, and consequently cut each other at right angles. In deep valley intersections the walls are beset with picturesque rocks, frequently cleft, as near Kreuznach (*pl.* 49, *fig.* 9). In Sicily the variegated sandstone presents spacious caves (*pl.* 52, *fig.* 2). A sandy soil is produced by its weathering, well adapted to the growth of the oak and the pine.

This group is extensively distributed. It occurs of great extent in England, where it is known as new red sandstone ; in Germany it is found in the Spessart, Odenwald, on the Rhone, in the Black Forest, in the Jura Chain, and on the west side of the Alps ; also in France, Poland, United States, &c.

b. Muschelkalk Group. White sandstones predominated in the last group, limestones of various degrees of purity do the same here ; they form the principal masses, and are accompanied by ferruginous brown limestone, fœtid lime, magnesian lime, clay sand marls, gypsum, karstenite, and rock salt. The purest limestones are generally met with in the middle of the group, which, receiving an addition of clay, becomes approximated to marly lime. Numerous individuals of few species constitute the fossils. The subdivisions are distinguishable, well defined by their palæontological character.

The lower subdivision is indicated by marly limestones, not of a thick.

but of an undulating and contorted stratification. These limestones sometimes alternate with bituminous and sandy limestone, tripoli, marly limestone, cellular limestone, &c. These masses generally appear in the lower portion of the subdivision, gypsum, karstenite, and rock salt occupying the higher. Magnesian limestone and dolomite are also found, and at times in immense beds. The former is sometimes much decomposed; the carbonate of iron to which it owes its blue color passes by oxydation into hydrated oxyde of iron, which penetrates the rock and colors it yellow, while the hydrated oxyde of manganese, resulting from the carbonate of manganese, is separated in black or dark-brown dendrites. Immense beds of these limestones are often entirely free from fossils; single layers are nevertheless characterized by *Buccinum gregarium*, *Dentalium læve*, *Terebratula vulgaris* (*pl.* 38, *fig.* 10), and *Myophoria vulgaris* (*fig.* 9); metallic minerals are calamine, galena, and brown iron-stone.

The middle subdivision is characterized by purer limestones, of light or dark color, which are often colored reddish in weathering by the decomposition of carbonate of iron. They form immense beds, which appear to be almost entirely composed of shells, the principal material of which has been furnished by *Terebratula vulgaris* and *Encrinites liliiformis*. The stem-joints of the latter, shown in *fig.* 7, are entirely converted into calcareous spar, and the axis of these pieces coincides with the axis of the rhombohedrons, after which the former is cleavable. The heads of such *Encrinites* (*fig.* 6) are but rarely found, having generally been separated by destructive external influences.

The upper subdivision contains impure marly limestones of earthy, somewhat plane fracture, having a great tendency to the formation of spheroids, and separated by clay or marl masses. Single beds consist of magnesian limestone, dolomite, and ferruginous brown limestone. The fossils here met with are particularly *Ceratites* (*Ammonites*) *nodosus* (*fig.* 11), *Terebratula vulgaris* (*fig.* 10), *Myophoria vulgaris* (*fig.* 9), *Avicula socialis*, *Lima* (*Plagiostoma*) *striata*, *Nautilus bidorsatus*, *Pecten lævigatus* (*fig.* 8), *Encrinites liliiformis* (*fig.* 6), together with teeth and bones of Saurians and fishes. These fossils occur in a somewhat singular manner: they do not lie, as in the middle division, sown indiscriminately in the strata, nor in single strips in the beds, as in the lower, but more on the faces of separation so as to lie half in the limestone, half in the clay slate, which separate the limestone strata.

The muschelkalk is very distinctly stratified, but traversed by less regular cleavages, which sometimes widen into caves. Like the variegated sandstone, it mostly forms flat troughs bounded by gently curved saddle formations. Higher ridges have generally rectilineal contours with rooflike slopes. The weathering of the muschelkalk consists of a mechanical division, and contributes little to the formation of a soil: the subordinate clay masses are of more account in this respect. Springs are rarely found at high levels, more at low; they sometimes contain a proportion of salt when connected with deposits of rock salt. The upper division is not abundant, while the middle and lower are widely diffused. The muschelkalk

is entirely wanting in England; on the other hand, it occurs in extraordinary development in Germany.

c. Keuper. (Marnes irisées; Red marls.) This group exhibits a considerable resemblance to the variegated sandstones, especially to the upper division. The principal rock species are clays, marls, and sandstones of various colors. Associated with these are quartz rock, ferruginous brown limestone, clay quartz, and many others; subordinate are gypsum, karstenite, rock salt, and coal. Where the group is complete three divisions may be established. The lower, that of the loamy coal and of rock salt, consists principally of slate clay, loam, and a highly fossiliferous sandstone (*equisetum sandstone*). The sandstone is of inconsiderable compactness, of an oil-green color running into grey, of thin or thick stratification, and frequently mixed with scales of mica. Among the fossils it contains, are species of equisetum, ferns, mollusca, fish, and reptiles. The clays also are tolerably rich in organic remains, especially in plants and shells. Among the latter *Posidonia minuta* is characteristic of the lower division; remains of fish and reptiles are found in marl clay and clay marl. These principal masses are frequently accompanied by ferruginous brown limestone, dolomite, and cement stone, and contain loam coal, in which a good deal of pyrites is disseminated: gypsum, karstenite, and rock salt are subordinate masses. The middle division, that of the variegated marls and gypsum, is principally composed of clay and clay marl. The clay occurs in the form of shale, marl clay, and loam, frequently containing nodules of pyrites and argillaceous carbonate of iron. The clay and lime marl are worthy of note on account of the minerals they contain: among these are iron pyrites, lying scattered in the most beautiful crystals, calcareous spar, quartz, verdigris, and mountain blue: remains of fish and reptiles with the coprolites (petrified excrement) of the latter, characterize the fossil fauna. Accompanying masses are clay quartz, quartz rock, and dolomite: subordinate are karstenite and gypsum.

Sandstones prevail in the upper division, both fine-grained clay sandstones and quartzose. The argillaceous sandstone is of various colors of grey, red, and violet, producing the most diversified markings by their combinations. It contains vegetable remains, on which account it has been called rush sandstone.

The quartzose sandstone of yellow bluish or ferruginous color is occasionally dotted with white feldspathic particles, and sometimes includes pieces of silicified wood. Another sandstone with an argillaceous, calcareous, or marly cement, is of very coarse grain, giving to it the appearance of a conglomerate: it is this which has been named *arcose* by Brogniart. A clay, marl clay, or slate clay often occupies the rank of a principal member, although it must be included among the subordinate: it also contains the same *Posidonia minuta* which characterizes the lower division.

The Keuper is generally well stratified. The dolomite and magnesian limestone have a conspicuous secondary cleavage, often giving rise to the formation of caves. The thickness of this group amounts to about 1200

feet; its mountains may vary much in appearance according as one or the other rock species predominates. They are generally spherically convex, with irregular valleys and deep ravines; the protruding rocks have much similarity to those of the variegated sandstones. Ore veins have not as yet been found in the Keuper. The soil resulting from the weathering of the marls is of great fertility, owing to the amount of lime. Springs are not abundant. The Keuper is found in England, Germany, Lower Saxony, Thüringia, Swabia, the Jura; also in France, Alsace, &c.

Pl. 46, *fig.* 11, exhibits a section of the rock salt formation as it occurs in Würtemberg. The strata of the Vosges sandstone are indicated by *a* and 1, and those of the incumbent sandstone by *b* and 2. Then follows the muschelkalk, *c*, with the lower 3, the middle 4, and the upper division 5; upon these rests the Keuper, *d*, with its three subdivisions, 6, 7, and 8: the whole is covered by the lias.

Fossils of the Rock Salt Formation. The fossils characteristic of the individual groups and subdivisions have already been mentioned; it remains now to notice some of rare occurrence, worthy of remark on account of their palæontological significance.

The fishes peculiar to the muschelkalk belong to the *Hybodontes*, a family of Plagiostomes, which enter here and pass off the stage in the chalk. They had bony spines in the dorsal fins, which are frequently well preserved. These ichthyodorulites have decided longitudinal grooves and two rows of strong serrations: *Hybodus tenuis* (*pl.* 40, *fig.* 4).

The teeth of the Hybodontes have a central larger lobe accompanied on each side by smaller decreasing ones, where covered by enamel they exhibit longitudinal grooves, the roots being broad and porous. The genus *Placodus* is peculiar to the muschelkalk, in which only teeth and a few bones have been found. This genus is characterized by small, obtuse, conical intermaxillary teeth, and a vomer, with broad, much depressed dental plates. *Pl.* 40, *fig.* 5, represents an entire upper jaw with teeth and vomerine plates of *Placodus andriani*, found in the muschelkalk near Bamberg. Other remains are of *Saurichthys mougeoti*, &c. Rhomboidal scales of ganoid fishes, and especially *Gyrolepis*, are found in the muschelkalk: *G. alberti*, *fig.* 7*a*.

The family of Labyrinthodonts, exhibiting relations to both Batrachia and crocodiles, is one of exceeding interest to the zoologist. They possessed a rough, depressed skull, with long conical teeth implanted in distinct sockets, and some of the anterior developed into formidable tusks. The exterior of the tooth is longitudinally furrowed, and a transverse microscopical section exhibits the most complicated foldings of dental tissue. A somewhat similar structure of less complexity is found in Ichthyosaurus, and some of the recent species of Lepidosteus. *Fig.* 8, *pl.* 40, represents the skull of *Mastodonsaurus jaegeri*, a labyrinthodont found in the keuper: *fig.* 9*a* is a detached tooth, *fig.* 9*b* a transverse section of the same.

Tracks of birds and of other less decided vertebrata have been found in the new red sandstone of Connecticut (*pl.* 41, *fig.* 32). Upwards of 70 species of such *ichnites* have been established by Hitchcock. Some of these tracks

are over 15 inches long, and 4 to 6 feet apart, indicating a size of enormous dimensions. A discovery of bones of birds in this formation has been recently announced.

Somewhat similar tracks of a different character have been found at Hildburghausen. They were sunk in a clay interposed between the strata of the variegated sandstone, the sandstone itself exhibiting the cast of the track (*pl.* 41, *figs.* 31[a], 31[b]). They are batrachoid in their character, and were produced in great probability by Labyrinthodonts. The imaginary animal which produced these tracks was formerly known as the *Chirotherium.* Some fossils characteristic of the English saliferous system, which belong in this place, are *Producta horrida* (*pl.* 42, *fig.* 32); *Retepora virgulacea* (*fig.* 33); *Terebratula globulina* (*fig.* 34); *Terebratula* (*fig.* 35); *Pecten radialis* (*fig.* 36); *Avicula gryphæoides* (*fig.* 37); *Axinus obscurus* (*fig.* 38); *Retepora flustracea* (*fig.* 39), and a fish, *Palæothrissum macrocephalum* (*fig.* 40).

Oolitic or Jura Formation. The Jura includes all strata between the rock salt or new red sandstone and the cretaceous system. The principal rock species are an oolitic limestone, clays and marls of tolerably uniform color, and a light-colored sandstone. Dolomite occurs in large masses as a secondary species. Fossil remains, especially animal, are very abundant, both terrestrial and fluviatile. Stone coal occurs in various parts, as also carbonate and hydrated oxyde of iron. Three groups may be distinguished.

a. The Lias (Calcaire à gryphites arquées, Marnes bleues inférieures, Terrain liasique). The principal species are clays and marls with gryphital limestone; the clays and marls in the form of shales, loams, clay marls, sandy marls, and calcareous marl shales, these mostly penetrated by carbonaceous particles, and inclosing nodules of sphærosiderite. In the Alps the slate clay is transformed into clay slate and calcareous clay slate.

The limestones are more or less pure, often containing iron pyrites and grains of earthy chlorite, fœtid limestone, marly limestone, and sandy limestone.

Among the accompanying masses are sandstones of various colors and grain, which have much similarity to those of the keuper. Subordinate masses are gypsum, karstenite, rock salt, carbonaceous strata, anthracite, graphite, bituminous shale, drawing slate, and various iron-stones.

The sandstone, as also an oolitic marly red iron-stone, contains many fossils, of which *Gryphæa cymbium* and *arcuata* are most characteristic and important. The thickness of the group varies from that of a few feet to whole mountain masses. Ore veins are of rare occurrence and slight importance. A few sulphur and saline springs are occasionally met with.

This group is distributed in England, Germany, France, and Spain.

b. Jura Limestone. This is greatly developed in England, and there includes all strata lying between the Lias and the so-called Purbeck limestone. Oolite is a limestone composed of rounded spheroidal grains of various size, somewhat similar in character to a sandstone, and probably

produced in the same way. Clays and marls accompany it, and separate the various lime strata. Subordinate masses are sandstones, gypsum, karstenite, rock salt, and carbonaceous masses. This group is divisible into three principal divisions.

The Lower Oolite. This is bounded inferiorly by the lias, superiorly by the Oxford clay, and embraces marly, sandy, compact, or oolitic limestones, and also true oolite, whose beds alternate with clays and marls. The limestones are generally light-colored, turning to ferruginous in exposure, this being caused by the presence of carbonate of iron. Bitumen causes a grey color. In England this division includes conspicuous beds of fuller's-earth. The sandstones are conglomeratic, calcareous, marly, , and ferruginous, with veins of fibrous carbonate of lime and arragonite; some are finely granular and quartzose, or passing into argillaceous quartz. Argillaceous sphærosiderite and oolitic marls are subordinate species.

The thickness of the oolite of the Jura amounts to from 1000 to 3000 feet. In England, where the formation is highly developed, the following succession of strata occurs. Lowermost of all is the inferior oolite, separated from the great or Bath oolite by an immense bed of clay, exhibiting the character of fuller's-earth (Terre à foulon). This great oolite is a partly compact oolitic, partly coarsely granular limestone, containing entire beds of corals. Between the great oolite and the fuller's-earth there is, in the vicinity of Stonesfield, a bed consisting of marly sandstones and loose sand, with many concretions. This is the so-called Stonesfield slate, interesting from its containing the first remains of fossil mammalia. Next to the great oolite comes a stratum of marly clay, becoming sandy above, the Bradford clay, of a blue color, upon which rests the Forest marble, a limestone full of shells. On the Forest marble lies a thin stratum of slaty, coarsely granular limestone, the Corn-brash. *Belemnites giganteus* and *canaliculatus*, *Ammonites Macrocephalus*, &c., are characteristic fossils.

The middle formation, which embraces the Oxford clay and the coral-rag, contains purer compact limestone of white or ochre yellow color, calcareous slate or lithographic stone; oolitoid limestone, which lies intermediate between compact and oolitic, and often entirely filled with fossils; marble of various colors; marl and marl lime, of darker colors, owing to the presence of carbonaceous matter; dolomite and sandy limestone.

Subordinated are iron-stone in rounded great or small grains, gypsum, karstenite, rock salt, and coal of poor quality.

Immediately on the upper layers of the English inferior oolite there lies a stratum consisting of calcareous concretions cemented by marl, and bearing the name of the Kelloway rocks. Upon these lies a blue clay, the Oxford clay, containing thin lime and marl beds, and calcareous concretions. Next comes the calcareous grit, a calcareous loose sandstone. This is succeeded by the coral-rag, and this by the pisolitic lime, an oolitic limestone with grains and nodules of iron-stone.

The fossils characteristic of this group are *Avicula pectiniformis*, the corals of the coral-rag, *Astræa helianthoides*, *Melania striata*, &c.

The upper formation [*Kimmeridge clay* and *Portland oolite*] contains purer

limestones, like oolite, marly and sandy limestone, the latter often accompanied by clayey, sandy, and marly masses, often colored green by chlorite; also dolomite and fine grains of iron-stone.

In England the clay (Kimmeridge clay) lies under the limestone (Portland stone), in other places the former is replaced by sandy deposits. This Portland stone or Portland oolite contains species of Nerinea and Pterocera.

c. Wealden Group. This embraces the *Purbeck marble, Hastings sand,* and *Weald clay,* placed by some geologists in the cretaceous system. The accompanying strata are marls, slate clay, bituminous shales, marl clay, clay marl sandstone, iron sand, quartz rock, clay quartz, fœtid limestone, shelly conglomerate, and argillaceous iron-stone: these contain remains of fluviatile animals. Beds of stone coal sometimes in considerable thickness are occasionally met with. In England the group attains a thickness of between 900 and 1000 feet.

The Purbeck strata occupy the lowest position, and consist of limestones which alternate with slate clay. This limestone appears to consist almost entirely of the shells of Paludina and Cypris, evidently indicating a fluviatile origin. Between these strata are found remains of reptiles and especially of Chelonia. The Hastings sand lies above the Purbeck beds, and consists principally of a quartzose iron sand alternating with sandy clays and marls. Here also are found beds of iron-stone, stone coal, and numerous remains of extinct colossal reptiles.

The Weald clay overlies the Hastings sand, and contains strata of a bluish potter's-clay, alternating with thin layers of a limestone filled with fossils that are very similar to those of the Purbeck marble.

Pl. 46, *fig.* 12, exhibits a section of the oolitic strata as it occurs in England.

The entire formation rests on the strata of the keuper (red marl) *a;* immediately on this lies the lias, *b,* which supports the true Jura limestone with the Oxford, *c,* and Portland, *d,* strata. The fresh water formation (Wealden) is shown in *fig.* 17 of the same plate.

In *fig.* 12, 1 indicates the lower lias strata, 2 the lias or gryphite limestone, and 3 the upper lias shale. Then follow the strata, 4, 5, 6, belonging to the lower oolite: after these the fuller's-earth, 7; the Stonesfield slate, 8; great oolite, 9; Bradford clay, 10; Forest marble, 11; Corn-brash, 12; the Kelloway rocks, 13; the Oxford clay, 14; Calcareous grit, 15; Coral-rag, 16; Oxford oolite, 17; Kimmeridge clay, 18; Portland stone, 19. In *fig.* 17, 1 indicates the Purbeck marble; 2 the Hastings sand; and 3 the Weald clay.

The Jura formation in France forms the figure 8, the southern ring being completely closed. In the centre of the ring are elevated the granite masses, and the trachyte of Auvergne, about which the Jurassic members lie like a cloak. The northern ring incloses the Paris tertiary basin, forming a trough in which the latter is deposited. It is entirely crossed by an artificial canal. The lias contracts considerably, but occupies a greater extent on the western borders of the Vosges. It commences to the northwest of Luxemberg (*pl.* 44, *fig.* 6, and *pl.* 46, *fig.* 16), and passing by this place grazes Metz and Nancy, bends to the eastward at Dijon, and ends near Besançon.

Over it lie the strata of the Jura proper, whose western border passes by Rheims, Troyes, and Auxerre, and almost reaches Lyons.

The Swiss Jura occupies a curve extending from Schaffhausen to below Geneva. It there forms high rock-walls furrowed by deep valleys of elevation, more abundant in the northern than in the southern portion. These valleys generally permit the older masses to emerge from under the newer. The newer strata form high lips with steep declivities, as shown in a valley of the French Jura (*pl.* 46, *fig.* 13).

The structure of these valleys may be explained by a cross-section of the valley of Bärschwyl in the Solothurn Jura (*pl.* 46, *fig.* 14). The bottom of the valley is formed by the gypsum bed of the keuper (6), towards which the keuper strata slope on both sides. Parallel to these are newer and newer strata, as the lias 4, the lower oolite 3, the Oxford marl 2, the Portland and coral lime 1. These limestones, which are little affected by the decomposing influences of the atmosphere, form the precipitous lips of the valley.

The Swiss Jura forms an entire system of strata curves separated by such valleys of elevation. The latter appear parallel for small extents, but in their general direction they radiate from a point not far from Basle. The deeper the fissure, the older is the rock which forms the bottom of the valley, and the more rugged the appearance of the whole. *Pl.* 46, *fig.* 15, is a section of a portion of the Swiss Jura. The Portland stone and coral-rag are indicated by 1; 2 represents the Oxford clay; 3 the lower oolite; 4 the lias; and 5 the muschelkalk. The chain of the Weiss-stein, A, sinks its valleys only to the Oxford clay; the valleys of the Hauenstein, B, reach to the lias, as also do those of the Passwang, C. In Mont Terrible they extend down to the muschelkalk, which is elevated in the middle of the valley, D. The lips (*a*) formed by Portland stone and coral-rag represent the Hosefluh (*a*), and form a valley at the bottom of which lies Bärschwyl (*b*). Schönthal (*c*) lies on the lias of the valley of the Hauenstein. The same lias extends under the Jura lime, cropping out first at Passwang and finally in the valley slope of Mont Terrible. The Renken (*e*) on the one side corresponds to the Rehhag (*d*) on the other.

The German Jura is a continuation of the Swiss: it begins at Schaffhausen, and extends through Franken into the vicinity of Bamberg and Baireuth (*pl.* 46, *fig.* 16). It describes a great arc, whose radius falls far in the interior of Germany. The strata of the Jurassic rocks fall in the same direction with this radius. The German Jura is divisible into three classes: *the black*, which consists of lias, and borders the entire series; *the brown*, whose strata correspond to the Jura proper, or the inferior oolite; and *the white*, whose masses are formed by the strata which lie over the coral-rag.

In the Franconian Jura, all the coral reefs, which compose a great proportion of the limestone masses, are converted into dolomite, having there a thickness of several hundred feet. In this transformation most of the organic remains are so much affected as to be scarcely appreciable, except in certain hollow spaces filled with a loose and finely-divided

limestone, called mountain milk. The whole dolomite series is traversed by extensive fissures, from which numerous caves have arisen, celebrated for the bones imbedded in their tertiary contents. Among these caves are those of Streitberg, Muggendorf, and Gailenreuth. The Solnhofen slate, or lithographic stone, is an important member of the Franconian Jura. This is a very fine-grained limestone, of a yellowish color, and contains many fossils in an extraordinary degree of preservation. It overlies the coral-rag. The Alpine Jura exhibits a very highly complicated structure, its masses being so much modified by abnormal rocks as to render it a matter of exceeding great difficulty to draw a comparison between the strata as they occur here and in other localities.

Fossils of the Jura. The fossils of the entire Jura formation exhibit the most interesting and varied character. Fucoids occur in great number, of which, however, only one species is sufficiently well preserved to be noteworthy. This is *Baliostichus ornatus* (*pl.* 38, *fig.* 12), an unjointed sea weed, with branching sporangiæ, and with the surface divided into lozenge-shaped areas, arranged in spiral rows. It occurs in great beauty in the Solnhofen limestone slate. Conspicuous among the Cycadeæ, a form intermediate between that of the ferns and that of the Coniferæ, we have the Zamiæ, as *Zamia pectiniformis* (*fig.* 13), in the Stonesfield slate.

The Cycadites, or Mantelliæ, are known by their almost globular stem, covered with lozenge-shaped leaf scars, broader than high, and disposed in spiral rows. *Cycadites* (*Mantellia*) *megalophyllus* (*fig.* 14) is found in the limestone of the Isle of Portland. *Mammillaria desnoyersi*, a species of an ambiguous family, is represented in *fig.* 15.

The coral polyps, which existed in great number in the transition rocks, but disappeared entirely in the entire trias period, again make their appearance in great profusion. The Astrææ, which also occurred in the transition, here play an important part. The most abundant species is *Astræa helianthoides*. *Labophyllia semisulcata* (*pl.* 38, *fig.* 16) is the most important representative of its family. Two genera of pedunculated echinoderms or Crinoidea are conspicuous: *Apiocrinites* and *Pentacrinites*. The former genus, possessing a very large pelvis, is exhibited only in pieces of the stem, and occasionally the pelvis without arms: *Apiocrinites mespiliformis* (*figs.* 17 and 18). An interesting species of *Pentacrinites*, *P. subangularis*, is shown in *figs.* 19 and 20. These have a pentagonal column, upon which arms, variously divided and subdivided, are supported on a very small pelvis; they are peculiar to the lias, while the *Apiocrinites* are found in the coral-rag.

The Echini, or sea urchins, are conspicuous in the Jura formation. These have a more or less spherical shape, and are covered with calcareous plates with tubercles, upon which are jointed spines of various degrees of development. These may be conical or club-shaped, and may vary much in size. The shell is divided into regular patterns by the pores through which the animal extended its ambulacra or organs of motion. The large oral and anal apertures have different positions in the different families The *Cidarites* have the anal and oral apertures diametrically opposite to

each other, and occupying respectively the centres of the vertex and base. The shell is furnished with large warts, on which are set large club-shaped spines, which, however, are generally broken off and dispersed. We find *Cidaris* (Hemicidaris) *crenularis* (*pl.* 38, *figs.* 21[a] and 21[b]) in the coral-rag, together with species of *Cidaris blumenbachii* (*fig.* 22). The zones on which the ambulacra stand generally run to a point. This, however, is not the case in *Dysaster;* here the rays unite in two points at no great distance from each other. The mouth of Dysaster lies anteriorly and below, while the anus is situated in the posterior border: *D. capistratus* (*fig.* 23), from the Oxford clay. The genus *Clypeus* is characterized by a rounded form, a mouth on the inferior surface, a lateral anus situated in a furrow above the mouth, and by the convergence of the ambulacral areæ to a point in the vertex. *Clypeus hugi* (*fig.* 24) is found in the restricted Jura group. The genus *Diadema*, of which *D. seriale* (*fig.* 25) is found in the lias, is also of spheroidal form, and has ambulacral areæ disposed in pairs, which run very regularly to the upper part. Two series of tubercles stand between the ambulacral areæ, all appearing to have borne spines.

A few species of the genus *Spirifer* recur in the lias only to disappear from the fossiliferous series; *S. walcotii* (*fig.* 26) is met with most frequently in gryphital limestone. In the Jurassic rocks, *Terebratulæ*, in great number, appear to replace the Spirifers; thus *Terebratula numismalis* (*fig.* 27) occurs in the lias, *T. globata* in the inferior Jura, and *T. impressa* (*fig.* 28), as also *T. thurmanni*, in the Oxford clay.

Of Monomyaria, *Ostrea* (oysters) here make their first appearance. They form entire banks, as at the present time. The genus *Ostrea* has a toothless hinge, through which passes a cavity containing a ligament, with deep muscular impressions. *Ostrea marshii* (*fig.* 29) occurs abundantly in the Oxford clay, and *O. deltoidea* (*fig.* 30) in the Kimmeridge beds.

The *Gryphææ* are closely allied to the oysters, and are distinguished by the greater curvature and spiral twist of the beak of the larger shell. Two species are found in the lias, *Gryphæa arcuata* (*fig.* 31) and *G. cymbium*. *G. dilatata* (*fig.* 32) is met with in the Oxford clay, and *G. virgula* (*fig.* 33) in the Kimmeridge marl.

Plicatula is another genus allied to *Ostrea*. The shell is regularly plicated, and the beaks are not projecting; they are found in the lias: *P. spinosa* (*fig.* 34).

Of the Pectens, *Pecten lens* (*fig.* 35) is found in the lower oolite, *P. disciformis* (*fig.* 36) in the middle oolite, and *P. personatus* (*fig.* 37) in the lias.

The genus *Perna* differs essentially from the preceding in shape, in the long hinge, and in the extensive emargination in the anterior portion of the shell: *Perna mytiloides* (*pl.* 38, *fig.* 38).

The thick-shelled *Trigoniæ* have considerable resemblance to the *Myophoriæ* already referred to under the muschelkalk. They are more or less triangular, and have long, laterally compressed and furrowed cardinal

teeth, of a V shape. *Trigonia navis* (*fig.* 39) characterizes the upper lias, and *T. clavellata* (*fig.* 40) the Oxford marl.

Pholadomya has a thin shell, open on both sides, with opposed beaks, but no teeth. *P. exaltata* (*fig.* 41) is peculiar to the Oxford clay.

Diceras possesses a very thick shell, running out into sub-spirally twisted beaks, and a hinge whose ridges exhibit some resemblance to a human ear: *D. arietina* (*fig.* 42).

Astarte has nearly circular valves shutting close together, and two cardinal teeth. It fills entire beds of the coral-rag, known as the Astarte limestone: *A. elegans* (*fig.* 43).

The *Nuculæ*, shells belonging to the family *Arcaceæ*, are extensively distributed in the Jurassic strata. They are small, regular shells, with four toothed hinges: *Nucula hammeri* (*fig.* 44, *a* and *b*). The genus *Pinna* is an elongated equivalve shell, whose beaks end in a point, and whose hinge margin is toothless. *P. hartmanni* (*fig.* 45) is found in the lower lias.

Pterocera oceani (*fig.* 46) is peculiar to the Portland limestone. This genus possesses a thick shell and a short axis. The oral aperture is narrow, and runs out above into a long canal. The external lip is expanded into a digitated wing. The *Pleurotomaria* have a thick, conically spiral shell, and a narrow quadrangular or rounded aperture, with a deep incision in the external margin, which distinguishes it from Trochus: *P. conoidea* (*fig.* 47) from the lower oolite.

Nerinea, a gasteropod genus, peculiar, excepting in one species, to the Jura, has a long conical, often cylindrical, spiral shell with very thick walls, and having highly characteristic internal folds. Certain species occur in great numbers of individuals, as *N. suprajurensis* (*fig.* 48), one turn of which is exposed in longitudinal section. *N. mosæ* (*fig.* 49), and *N. godhallii* (*fig.* 50); *fig.* 51 is a longitudinal section of the latter. The most conspicuous Ammonites are *Ammonites bucklandii* (*fig.* 52) in the lias; *A. catena* (*fig.* 53), also in the lias, and *A. striatulus* (*fig.* 54) in the lower oolite.

There are a few species of the Nautilus family, as *Nautilus lineatus* (*fig.* 55), in the lower oolite. Here, as also in the muschelkalk, we find the beaks of cephalopods, known as Rhyncholites, or Conchorhynchs. These Rhyncholites exhibit a striking similarity to the mandibles of parrots or of Cheloniæ. *Pl.* 38, *fig.* 56, is a lateral view of one of these Rhyncholites.

The fossil known as *Belemnites*, belonged, in all probability, to a cephalopod, and, like the so-called *ossa sepiæ*, was an internal framework inclosed by the softer parts of the animal. They are generally conical bodies of various shapes, mostly of a crystalline texture, the crystals radiating from the longitudinal axis of the Belemnite (*fig.* 58*c*). They run out below into a more or less acute point, and at the upper part exhibit a conical excavation. The ink bag of the Belemnite has been found in this cavity in a state of preservation sufficient to admit of the use of the contents in drawing the fossil itself. The internal structure of the cavity may sometimes be ascertained in the upper portion: in it was inserted an

alveolus or phragmocone, with a chambered shell and a sipho quite like that of *Orthoceratites* (*fig.* 61 and *fig.* 58*b*). A rarely preserved horny plate was connected with the posterior face of the alveolus (*figs.* 57 and 58, *a*).

Belemnites paxillosus (*fig.* 59, *a*) occurring in single strata of the lias in countless numbers, is readily distinguished by the channelled apex, shown in cross-section by *fig.* 59, *b*. *B. giganteus* (*fig.* 60) is of immense size, sometimes over one foot in length: it characterizes the lower oolite. *B. hastatus* (*fig.* 61) has a hastate cone, and is found in the Oxford marl.

The above-mentioned view of the morphological character of the Belemnites does not, however, explain the import of the chambered shell and the sipho. A more careful investigation of allied structures, both recent and fossil, renders it very probable that the animal itself lived in these chambers like Nautilus and Ammonites, a view which the occurrence of the sipho goes very far to substantiate. The shell of the camerated portion is very thin and exceedingly fragile, for which reason it is inclosed by a thicker, more solid portion, as in Nautilus. This protecting cover is the conical body or rostrum so often met with in a petrified state, and, in all probability, has been secreted from a mantle. The animal, probably, inhabited the upper chamber, as in the Orthoceratites, Ammonites, and Nautili; its mantle was probably analogous to that of the recent nautilus. This view also explains how it is that the solid portion is composed of a succession of vertical layers, each one corresponding to a chamber. When the animal formed a new cell, this had to be enveloped by an additional external protecting cover, which, of course, embraced the portion already existing. The greater the number of chambers in the phragmocone, the thicker and longer the solid portion, and the greater the number of layers in the latter.

The strata of Solnhofen, which inclose so large a number of palæontological treasures, also exhibit fossil insects, belonging especially to the family of the Libellulidæ (*fig.* 62). The characteristic features of these insects, as the antennæ, the masticatory apparatus, the legs, and the nervatures of the wings, are not sufficiently well preserved to permit us to compare them very closely with the existing members of this family. Many of them are of colossal size, even attaining a length of six or more inches.

The Jura strata reveal a new page of fossil ichthyological history. We here find the heterocercal fishes, or those with an unequally lobed tail, receding into the background, and the homocercal coming forward in increasing numbers. The essential difference between the two consists in the prolongation of the vertebral column along the upper edge of the caudal fin in the former, while in the latter, the extremity of the body occupies a position nearly symmetrical, with respect to the two lobes or halves of the tail.

The teeth of *Strophodus*, a genus of the *Cestraciontes*, are depressed, truncated on both sides, and elevated in the middle, without a central longitudinal fold. Their axis is somewhat twisted, and the surface sometimes striated or reticulated; the root is broad and porous. *Pl.* 38, *fig.* 63, represents a tooth of *S. longidens*. The genus *Pycnodus* is the most

abundant of the *Pycnodonts*. These were short and high fishes, with a strong skeleton. The eyes lay very high above the rather wide mouth. The dorsal and anal fins were of considerable extent, reaching to the homocercal caudal: *P. rhombus* (*fig.* 64).

In the family of the *Lepidoides*, the genus *Dapedium* is distinguished by a short and flat body, small head, and diminutive mouth, provided with sharp curved teeth. The fins are short and weak, the ventral and dorsal nearly opposite. The thick rhomboidal scales were covered with enamel, and connected by processes. *D. punctatum* (*fig.* 65) and *D. politum* (*pl.* 41, *fig.* 11) occur in the lias. The present creation exhibits few representatives of these fish with angular connected ganoid scales, the chief representatives being the North American *Lepidostei*, of which some ten species are known to naturalists. *Pl.* 41, *fig.* 12^a, represents one of these species; *fig.* 12^b, a portion of its jaw.

The species of *Megalurus* and *Aspidorhynchus* are conspicuous among the *Sauroids*. The former (*pl.* 38, *fig.* 66) have large rounded caudal fins, high dorsal, and large pectoral fins. Their shape is compact and stout, the head short, with a moderately large mouth, provided with thick conical teeth. *Aspidorhynchus* (*pl.* 41, *fig.* 13) was a very long, narrow, and cylindrical fish, with a long upper jaw projecting far over the under, both being furnished with conical acute and unequal teeth; the scales are higher than long, the dorsal fins opposite to the anal, and both very near the large forked tail. Both Megalurus and Aspidorhynchus are found in the upper Jura strata, the latter also in the cretaceous. *Pl.* 41, *figs.* 14–23, represent teeth of certain ambiguous fishes.

The reptiles of the Jura belong especially to the *Enaliosaurians*, represented by the genus *Ichthyosaurus* and *Plesiosaurus*. The Enaliosaurians are principally characterized by the fish-like vertebræ. These are flat at both ends, and conically concave (*pl.* 42, *figs.* 24 and 27), forming a long vertebral column by their union. The four feet of the animals are broad and flat, without either fingers or claws, being thus true paddles. The normal bones of the feet are subdivided much more than in recent forms. The sharp conical teeth stand in long grooves of the jaws, and each one inserted in a distinct socket, as in the crocodiles. The head also exhibits some resemblance to these latter animals.

The *Ichthyosaurus* (*I. communis*, *pl.* 41, *fig.* 26^a from the Lias) has been found of a length of 40 feet. The large head possesses a long acute snout, furnished with 120 to 160 conical grooved teeth (*figs.* 26, *b* and *c*), interlocking together on closing the jaws. The eyes are very large and circular, with a bony sclerotic, composed of several plates such as are now found only in birds and turtles. The vertebræ are numerous, those bearing ribs amounting to as many as 40. The short neck contains only from five to ten vertebræ. The ribs inclose the whole body, and are connected with a T-shaped sternum. The anterior extremities are more powerful than the posterior, both probably having been covered with angular plates of horn, while the body was naked. Like some recent fishes, the *Ichthyosaurus* possessed a spiral intestinal canal, which impressed the same character on the

excrements. These are frequently found fossilized, and are known as coprolites. They contain teeth, scales, fins, and bones of fishes, in large number, which, together with the general structure of the animal itself, allow us to consider the Ichthyosaurus as highly destructive to the animals with which it was associated, and to fish especially.

The *Plesiosaurus* is distinguished from the *Ichthyosaurus* by the possession of a very long flexible neck, provided with a much smaller head. The paddles were also longer and the tail shorter: *P. dolichodeirus* (*fig.* 25[a]). The teeth (*fig.* 25[b]) were conical and finely furrowed: *P. macrocephalus* (*pl.* 40, *fig.* 10).

The *Pterodactyles*, or flying saurians, are among the most extraordinary forms, either recent or fossil, known to zoologists: *Pterodactylus crassirostris* (*pl.* 41, *fig.* 35). They had a large head with very broad orbits, and unjointed bony sclerotics. The broad jaws are provided with long subulate teeth, inserted in special sockets. The long strong neck is set on a short trunk, which ends posteriorly in a thin short tail. The humerus is short and thick, the fore-arm more than twice as long. Upon the carpus is set a hand with powerful claws, the external finger being very long and falcate. The hind feet were tolerably long, thin, and attached to a feeble pelvis. The hind and fore-feet were probably united by a membrane, as in the Cheiroptera or bats of the present day, admitting of feeble powers of flight. The principal difference in the structure of the wings of the pterodactyle and the bat lies in the fact, that while the former has but one finger greatly developed, the latter has four.

The first traces of Mammalia are found in the Stonesfield slate, and probably belonged to carnivorous Marsupialia. Several genera and species have been distinguished, as *Phascolotherium bucklandii* (*pl.* 38, *fig.* 67, lower jaw).

The Jurassic fresh water formations are in some places, as at Neufchatel, replaced by marine limestones and marls. Of the fossils peculiar to the Neocomien, some of the most interesting forms will now be mentioned.

Of *Echinodermata*, *Holaster complanatus* (*Spatangus retusus*, *pl.* 39, *fig.* 13). The Holasters are cordiform, and possess curved ambulacral zones in the vicinity of the generative apparatus. The mouth is placed anteriorly on the lower side in a depression, the anus being situated behind and more towards the upper face. Other fossils of interest are *Trigonia caudata* (*fig.* 19), *Mytilus simplex* (*fig.* 28), *Turbo plicatilis* (*fig.* 35), *Pleurotomaria neocomensis*. The chambered cephalopods are represented by *Crioceras*, a genus characterized by its free turns: *C. duvalii* (*fig.* 38); also *Ammonites macilentus* (*fig.* 40); *Scaphites* and *Toxoceras* distinguished from each other and from *ammonites* by the character of their rolling up: *S. ivanii* (*fig.* 42) and *T. bituberculatus* (*fig.* 41).

In surveying the fossils of the Jura we observe a great variety of forms, among which the Saurians stand pre-eminent. The central figure of *pl.* 37, after Buckland, illustrates the extraordinary character and probable rapacity of some of the animals characteristic of the lias. In this representation *a* indicates the *Ichthyosaurus communis*; *b* *I. longirostris* about to

devour a *Dapedium politum, e; c*, a *Plesiosaurus dolichodeirus;* and *d*, two *Pterodactyles* fighting. At the bottom of the water are *Pentacrinites, f, Mollusca, Crustacea*, skeletons of various animals. *Ammonites* and *Nautili* sail about on the surface with outspread mantle. The shores are lined with *Cycadites, Coniferæ, Zamiæ*, &c.

Pl. 42, *fig.* 31, represents *Gryphæa incurva; fig.* 30, part of the jaw of a crocodile; *fig.* 29, *Pholadomya murchinsonii; fig.* 28, *Ammonites walcotii; fig.* 27, a dorsal vertebra of *Ichthyosaurus communis; fig.* 26, *Clypeus clunicularis; fig.* 25, *Cidaris intermedia.*

Cretaceous System. The petrographical character of the Cretaceous System is essentially different from that of the Jura. The chalk forms a highly characteristic feature, although it does not occur in all cases. In addition to chalk there are compact limestones, marl clays, sandstones, sand beds, and conglomerates, containing gypsum, karstenite, rock salt, iron-stone, and coal, as subordinate masses.

The cretaceous system exhibits different features in different localities, having reference not only to the petrographical character, but to the distribution of the fossils. Such deviations from the normal character in the latter respect are found in the Alps, the Carpathians, in Southern France, Spain, &c., which in all probability have been effected by climatic differences. Plants are not very numerous; the few that do exist belong both to land and marine forms; leaves of terrestrial dicotyledons frequently occur. Animal remains are found in great numbers, especially marine species, among which may be enumerated Corals, Sponges, Alcyonia, Siphonia, Echini, Crinoidea; more rarely shells, particularly Sphærolites, Hippurites, Turrilites, and Ammonites, which here disappear from the stage of animal life. The reptiles have become more similar to the present forms. The cretaceous formation is divisible into two groups.

a. Greensand (Grès vert), subdivisible again into two sections, the quadersandstein and the chalk marl. The quadersandstein consists of sandstones of very loose texture, occurring in some localities as sand beds. They are sometimes argillaceous, calcareous, or marly, sometimes ferruginous, or cemented by chalcedony: the colors are white, grey, and red; the lighter appear to predominate. The grain of these sandstones is of various character, fine, coarse, or conglomeratic. The sandstones themselves are occasionally traversed by veins of quartz, which remain in the weathered rock as intersecting elevations, and contain tree stems and shells. The accompanying clay beds are marly, and of a bluish color.

The lower regions of this formation are generally ferruginous, while the upper are of a greenish color, owing to the presence of chlorite.

Subordinate masses are granular clay, iron-stone, blue when fresh, brown when weathered, sandy argillaceous sphærosiderites occurring in nodules or their aggregations, stone coal, lignite, and bituminous wood.

The second formation, that of the chalk marl, consists of various clays and marls, with limestones. The marls occur as flame marl, chalk marl, and as marl clay, or clay marl.

The flame marl is sandy, coarsely earthy, and of various shades of grey

and yellow, whose uniformity is interrupted by dark spots, cloudings, veins, &c. A slight tendency to green is produced by the presence of a little chlorite. The chalk marl exhibits various shades of color, but not the markings so peculiar in the preceding; it is generally white, green, grey, or yellowish. The variegated clay marl, and marl clays, often exhibit a great similarity to those of the rock salt formation, and contain nodules and entire beds of fire-stone.

The limestones, often marly, are white and grey, more rarely blue and greyish black; the purer varieties have a conchoidal brittle fracture, and are frequently traversed by veins of calcareous spar; they are sometimes exhibited as marble or oolitic limestone, and are accompanied by clay or clay marl.

Subordinate masses are an iron-stone which is frequently mixed with green earth, gypsum, karstenite, and rock salt, all, however, only occurring in the marl.

b. White Chalk Group. This, also, is divisible into two formations, the lower of which is of most frequent occurrence. It is in this that the true chalk exists. The white color often passes into grey, reddish, or yellow, and the hardness varies from that of the chalk of commerce to that of compact limestone. Fire-stones frequently occur in nodules lying parallel to the planes of stratification, or in entire beds produced by the aggregation of the former. It consists, in great measure, like the chalk itself, of infusorial skeletons, recognisable by a good microscope.

Chalk rock comes near to the chalk proper, and consists of a white silicious limestone. The silex is not unfrequently separated in the form of nodules. Here belongs also the flag limestone, a compact rock of brittle fracture, and sometimes mixed with sand. The accompanying chalk marls are chalk white, and pass on the one hand into chalk, on the other into chalk rock. Dolomite is very rare; clay and loam beds occur between strata of firmer texture.

The upper formation is more seldom met with, and consists of Saugkalk, chalk (in Petersberg, near Maestricht) and a granular saugkalk of ochre yellow color. In these rocks there also occur nodules of freestone and of hornstone. A great variety of fossils is met with, among others, *Lacerta gigantea*, and *Pagurus faujasii*.

Above these limestones lie fossiliferous, earthy, sandy marls, of white, grey, yellow, green, or brownish colors. Clay and loam beds colored by greensand or oxyde of iron, occur as subordinate masses; also, a marly sandstone mixed with grains of earthy chlorite, a calcareous sandstone with many granules of lime, a calcareo-silicious conglomerate with fragments of shells, and a marly limestone.

The cretaceous formation is developed most completely in England, and has there been investigated most fully. A section of the stratification is exhibited in *pl.* 46, *fig.* 17. Beneath lie the strata of the Jurassic fluviatile formation; reckoned by many geologists among the cretaceous: they include the strata, 1, 2, 3. Upon these rests the lower formation of the first group: first the lower greensand, 4, with the gault, 5 (the blue clay bed):

then the upper green sand, 6, differing from the sand masses of the lower green sand by the presence of a much greater number of green particles. It contains many silicious and not very compact concretions called cherts. Next come the chalk marl, 7, the Grew-chalk limestones, 8, and the white chalk, 9.

The upper formation of the white chalk assumes quite a different character in the Pyrenees, in the Alps, and in the Apennines. Conglomeratic slaty sandstones, resembling grauwacke, mixed with mica, occur here. They are known by the name of Macigno in Italy, in Switzerland as Flysch and Vienna sandstone, and contain many vegetable remains, especially of Fucoids, for which reason they have been called fucoidal sandstones. Hippurites occur in the limestones, but not in the northern chalk rocks ; in the southern they are, however, found.

In the Apennines, a limestone and slate mass underlies, and contains large numbers of *Spatangus retusus*. Upon this rests the hippurite limestone, characterized by Hippurites, Radiolites, &c. Then follows the nummulite sandstone entirely filled with Nummulites ; and lastly, the fucoidal slate, Flysch or Vienna sandstone.

Recent investigations of the cretaceous formation in France have given rise to the following division of the strata :

On the neocomien formation lies the lower chalk, the *terrain aptien*, embraced by the upper strata of the latter, and separated from it by its palæontological characters.

Upon this is the *terrain albien*, consisting of the lower greensand and the gault, characterized by *Inoceramus concentricus* and *Trigonia aliformis*.

Then the chloritic chalk or the *terrain turonien*. It includes the upper green sand, the limestones of the upper formations of the first group (the *craie tuffeau*) and the chalk marl, and is decidedly characterized by the presence of Hippurites and Baculites. The senonian strata (*terrain senonien*) close the series, being composed of the true white chalk of both formations.

The stratification of the individual members of the cretaceous formation is much diversified : in the chalk rock it is very intricate, while in the quadersandstein it is exceedingly regular ; double rectangular cleavage traverses it in such a manner as to produce cubiform blocks. The thickness of the cretaceous often exceeds 1000 feet. It sometimes forms whole mountains, whose external appearance is affected greatly by the particular member which is present. When the softer varieties predominate, they possess a gently rounded exterior ; the chalk rock inclines to the formation of a spherical surface, and the quadersandstone to that of picturesque rocks. The chalk itself forms high cliffs, especially on the coasts.

The soil produced by the weathering of the quadersandstone is poor and sandy ; that resulting from the marl very warm, on account of the amount of lime ; for this reason it is well adapted to the growth of the vine. The springs are inconsiderable in number, and feeble in character ; some, however, are exceptions in being quite copious : a few are saline.

The cretaceous system is extensively distributed ; it is found in Denmark, England, France, Belgium, Germany, as in Mecklenberg, Lower and Upper Saxony, Westphalia, Bohemia, Franconia, and Silesia ; it likewise occurs in the chain of the Alps and Jura, in the Pyrenees, in Spain. Portugal, the Apennines, Sicily, Greece, Hungary, Galicia, Poland, Russia ; in Asia, on Mount Lebanon ; in Northern and Southern Africa. The cretaceous system of North America differs in many features from that of Europe. True chalk is entirely wanting, the series being represented by greensand, marls, and a shelly limestone often of great compactness. It occurs in New Jersey, Maryland, Virginia, North and South Carolina, Georgia, Alabama, Arkansas, and various other regions.

In Germany, the cretaceous extends along the northern sea coast, and from Westphalia towards the east ; it is very similar in character to the French system.

The lower strata are formed by the Hils clays (bluish clay with hard calcareous nodules), which are probably the equivalents of the upper part of the Neocomien formation ; upon these rest sandstones, of more or less thin stratification, and of different colors of brown and red, with no great compactness, even running at times into quite a loose sand bed : these appear to correspond to the lower greensand. The strata of the gault are not well recognised in North Germany. The beds corresponding to the upper greensand are known in Westphalia as very similar to those in England and France ; they are, nevertheless, principally replaced by flammen marl. Upon these lies the chalk marl, whose hard, marly, grey limestone, with alternating layers of clay, closes the highly fossiliferous series of the freestone chalk which occurs in such complete development in northern Germany on the Island of Rügen.

The lower chalk is developed in quite a peculiar manner in Saxony : it is there represented by masses of a fine-grained white, grey, or yellowish-brown quaderstein, whose regular fissures, cutting each other at right angles, form the delightful valleys of the Meissner uplands, or the Saxony Switzerland. Between the sandstone masses there passes a layer of limestone, readily splitting up into plates, known as the planerkalk, and appearing to correspond to the gault. The subjacent quadersandstone must in this case be considered as the equivalent of the lower greensand, and that above it as the upper greensand.

Fossils of the Cretaceous System. The chalk is very rich in fossils ; among polyps, a prominent form is *Hallirhoa costata* (*pl.* 39, *figs.* 1 and 2), a spongeoid hard body, with a large aperture in the upper pedunculated and often lobed expansion.

The infusoria play an important part in the chalk, forming entire strata. Here belong the Rhizopoda (*Foraminifera, Polythalamia*), whose almost microscopic calcareous test was at an earlier period looked upon as the shell of a minute cephalopod, to which it has an unmistakable resemblance The shell, which contained a series of minute apertures for the passage of the organs of motion, is divided into chambers, which do not communicate with each other, each one inhabited by a distinct animal. This fact,

while it negatives the cephalopod character, renders it probable that the shell formed a minute polypidom, inhabited by animals of a very low organization. The whole of the true chalk appears to have been formed from such shells. We need not be astonished at such abundance of infusorial shields when we reflect that *one* animal whose calcareous or silicious test may weigh $\frac{1}{10\,000}$th of a grain, is capable of so multiplying itself in thirty days, as that the sum of the resulting tests or shields shall weigh over 65,000,000,000 lbs., and be capable of covering a surface nearly fifteen square miles to a depth of two feet, with a density equal to that of water. The Rhizopods are divisible into various groups, according to the various position and character of the individual chambers. The *Monostegia* are shells with a single chamber; the *Stichostegia* have the chambers placed one above the other in a single straight or curved line; the *Helicostegia*, with chambers placed along an axis forming a spiral volute; the *Entomostegia*, with the chambers placed along two axes alternating with each other and rolled up into a spiral; the *Enallostegia*, with the chambers alternating along two or three axes, and not rolled up spirally: and the *Agathistegia*, or milliolites, in which the chambers are disposed spirally round an axis, each one occupying a semi-circumference.

Dentalina, which belongs to the Stichostegia, has a somewhat curved conical shell, consisting of spherical chambers, the latter often elongated. The single cells are separated from each other by no very deep contractions: *Dentalina sulcata* (*pl.* 39, *fig.* 3).

Textularia, of the order Enallostegia, has a conical and regular shell, with the round or wedge-shaped chambers arranged along two contiguous axes: *T. aciculata* (*fig.* 4).

The Helicostegia separate into two groups, according as the chambers are rolled up in a plane or in a turret. *Bulimina* belongs to the latter: *B. obliqua* (*fig.* 5). Between these and those whose turns lie in one plane, like the nautilus, stand the *Rotalina*, whose obliquely rolled columella is very short: *R. voltziana* (*fig.* 6). The *Cristellaria* exhibit the greatest resemblance to the nautilus, being a perfect miniature of the latter: *C. rotulata* (*pl.* 39, *fig.* 7). As *Lituites* is only a modified nautilus form, so *Lituola* may be considered as such with regard to Cristellaria. They are cristellaria whose cells suddenly lose the winding character, and run out in a straight direction: *L. nautiloidea* (*fig.* 8). The flat compressed shell of *Flabellina* is at first wound up very regularly, and afterwards expands in a foliated manner. The partition walls are at first simply curved, and afterwards interrupted: *F. rugosa* (*fig.* 9).

The infusoria hitherto considered are those found in the white chalk. In other calcareous masses of the cretaceous system allied forms occur, as in the nummulite limestone which occurs in the Pyrenees. The nummulites fill the above-mentioned series in countless numbers, and would be highly characteristic did they not also occur in the Hippurite limestone. The internal structure of the nummulite is often beautifully revealed on breaking open a piece of nummulite limestone, in which case it will most frequently happen that one or more of the shells will be split in two, as they are of

sufficient size (sometimes an inch in diameter) to permit this fracture (*fig.* 10). A nummulite consists of an aggregation of spirally wound chambers, separated from each other by obliquely disposed, almost vertical partitions. *Fig.* 11 is a cross-section.

Certain Echini are very characteristic of single beds of the cretaceous. In the white chalk *Galerites* is distinguished in this respect: *G. albo-galerus* (*fig.* 12). This genus belongs to the Clypeasters, known by their nearly conical shape, and by the occurrence of the ten-cornered mouth in the middle of the base, with the anus in the posterior border. The five ambulacral zones run directly from the vertex to the mouth. The plates are well defined, and possess feeble tubercles, upon which stand slightly developed spines.

The *Hippurites*, or *Rudistes*, come near to the *Brachiopoda*, and are highly inequivalved bivalves. The lower shell, attached either below or at the side, is much the larger, and is closed by a smaller operculoid valve, without hinge or ligament. The figure is very irregular, as they formed beds like oysters, and of course were obliged to accommodate themselves to the spaces left vacant by the contiguous individuals. The shells of the Hippurites are very thick, yet, nevertheless, so often destroyed that only stony casts, in the form of two cones, placed base to base, remained behind, and were known at an earlier period under the name of *Birostrites* or *Jodamia*. Considerable uncertainty was for a long time felt as to the true place of these animals in the scale, and the divisions in the lower part of the shell gave rise to the erroneous idea that they belonged among the cephalopods. This supposition is now, however, completely refuted, and the study of the closely allied *Crania* enables us to place it with a considerable degree of certainty among or near the brachiopods.

The Rudistes separate into several genera, particularly into the true *Hippurites* and the *Sphærulites*. The former have a very long conical lower shell, with acute base and several longitudinal furrows. The much smaller upper shell is very flat and operculoid, and this contributes to the formation of a simple conical stone nucleus: *H. organisans* (*pl.* 39, *fig.* 14) and *H. bioculata* (*fig.* 15).

The lower shell of *Sphærulites* is smaller and the upper larger than in the preceding. It therefore appears as two unequal cones, placed base to base, with ridged and often foliated surface: *S. ventricosa* [*Radiolites turbinata*] (*fig.* 16).

Among the true *Brachiopoda* may be mentioned *Crania*, whose small, almost circular shells, are attached by their lower portion. The lower shell is flat, and has a process, on whose sides are two deep muscular impressions, which also exist on the upper free conical valve; the process and valve impressions are sometimes wanting. The border of the shell is provided with warty elevations. *Fig.* 17 represents the inner part of the upper shell; *fig.* 18, the same from below.

Trigonia aliformis and *T. scabra* (*fig.* 20), and *Cardium productum* (*fig.* 21), represent their respective genera.

The *Ostraceæ* are quite different in form from that which we found to

prevail in the Jura; the family is here represented by *Exogyra*, differing from the displaced Gryphæa by the laterally bent beaks: *E. columba* (*fig.* 22) and *E. sinuata* (*fig.* 23).

Inoceramus comes rather near to the oysters; they are inequivalve shells, of tolerably triangular form. The opposing beaks are strongly bent, and the hinge has a number of indentations: *I. concentricus* (*fig.* 24) from the greensand.

Spondylus with inequilateral, spiny shells, has two teeth in the hinge, and two strong muscular impressions: *S. spinosus* (*fig.* 25) from the white chalk.

Pectunculus, represented in the upper greensand by *P. subconcentricus* (*fig.* 26), is a genus of shells, equivalve, and closing tight, the curved hinge provided with teeth, separated from each other by deep intersections, the cardinal area covered with broken lines, and the border provided with fine teeth. Closely allied to these is the genus *Nucula*; *fig.* 27 represents a cast of *N. pectinata* from the lower greensand.

The species of *Opis* have two very thick tapering cordiform valves provided with very long beaks, and a complicated hinge with a large compressed tooth: *O. elegans* (*pl.* 39, *figs.* 29 and 30), from the upper greensand.

The genus *Acteonella* is a characteristic representative of the *Gasteropoda* in the cretaceous. The individual turns of the shell embrace each other in such a manner as that the aperture occupies the entire length. The aperture is very narrow, and is contracted still more above by three thick ridges. *A. crassa* (*fig.* 31) is peculiar to the chloritic chalk. *Avellana* is much more universally distributed than the preceding, and is characterized by its short and rotund shell with crescentic aperture, and three strong teeth on the inner margin, the outer border with small long transverse teeth: *A. incrassata* (*fig.* 32) from the gault.

Rostellaria has a subfusiform or turreted spiral shell, with the upper part of the aperture ending in a long tube, and the margin dilated into a wing, or digitated, the wing sometimes falcate towards the apex. The species occur from the upper Jura to the present epoch. A characteristic species for the chalk is shown in *fig.* 33: *R. parkinsoni*. *Pterocera pelagi* (*fig.* 34) is peculiar to the white chalk, *Natica lyrata* (*fig.* 36) to the chloritic chalk.

The Cephalopoda of the cretaceous system present many points of interest. The *Nautilidæ* occur with simple windings and simple smooth partitions. The *Ammonitidæ*, previously so remarkable for the fringed and varied attachment of the partitions to the main shell, assume a new character in approximating to the earlier simplicity of the preceding family. At the first appearance of the Nautilidæ, it will be remembered that the single chambers were combined in various ways, either in a linear direction, as in *Orthoceratites*, or the axis a little curved at the vertex, and then continued in a straight line (*Phragmoceratites*) or rolled up below (*Lituites*), and subsequently entirely rolled up in a single plane, as in the true *Nautilus* and *Goniatites*. The opposite condition of things prevails in the ammonite

family. At first they occur as completely chambered shells, with the windings in the same plane and in contact with each other ; in the cretaceous system, when about to disappear from the fossiliferous rocks, they begin to exhibit the original character of the Nautilidæ. The *Crioceras* of the neocomien come very near to the true Nautilus (see fossils of the Jura). *Toxoceras* and *Scaphites* of the same beds stand further removed, as also do the *Hamites* of the gault. The *Baculites* of the Ammonitidæ correspond to the Orthoceratites of the Nautilidæ : in the former, the chambers with fringed or sinuated margins are superimposed along a straight axis. *Pl.* 39, *fig.* 43, represents *Hamites attenuatus*, and *fig.* 44, *Baculites anceps*, found in the middle chalks. Of the true *Ammonites*, *A. varians* (*fig.* 39) is found in the white chalk. The various forms of the Ammonitidæ just referred to, have had their turns all in the same plane. *Turrilites* has them in different planes, so called from being of a turreted form (*T. costatus*, *fig.* 45). This genus is distinguished from Helicoceras by having the turns in contact.

Belemnites mucronatus (*pl.* 42, *fig.* 22) is known by the deep emargination of the base.

The fishes of the cretaceous period exhibit a transition from the more ancient forms to those of the present day. *Pl.* 40, *fig.* 7^b, represents the quadrangular broad teeth of *Ptychodus latissimus*, hitherto only found in the white chalk. The ganoids become less abundant, and in their stead come cycloids and ctenoids. The scales of *Beryx* are represented in *fig.* 7^c.

A gigantic lacertan reptile is found in the upper cretaceous group of Maestricht, *Mososaurus hoffmanni*, as also some crocodilians ; the cretaceous of North America, likewise, embraces species of Mososaurus. The Maestricht beds also contain teeth of *Iguanodon mantelli* (*fig.* 11^b). But few remains of birds occur, a partial skeleton is shown in *fig.* 12.

Other fossils, characteristic of the English cretaceous, are *Pecten quinquecostatus* (*pl.* 42, *fig.* 13) ; *Apiocrinus ellipticus* (*fig.* 14) ; *Spongia cribrosa* (*fig.* 15) ; *Marsupites milleri* (*fig.* 16) ; *Inoceramus sulcatus* (*fig.* 17) ; *Trigonia alæformis* (*fig.* 18) ; *Cotillus brogniartii* (*fig.* 19) ; *Ammonites varians* (*fig.* 20) ; *Plagiostoma spinosum* (*fig.* 21) ; *Belemnites mucronatus* (*fig.* 22) ; and *Scaphites costatus* (*fig.* 23).

Tertiary Middle Series.

In ideal succession, the tertiary middle series lies immediately above the newest deposits of the secondary middle. This, however, does not always occur in nature, and although the tertiary beds are not found between the older rocks, they yet at times rest upon them, and even upon abnormal masses, by which they are not unfrequently pierced and overlaid. In the latter case, the abnormal must be the newer of the two ; it is generally basalts that present themselves among the tertiary in this manner.

The thickness of the tertiary is sometimes very considerable, as, for instance, on the Righi, 6000 feet high ; they also occur at considerable

elevations, although much more abundant in older lower regions, where they fill troughs or basins of the older rocks, or extend along the sea coasts. A crystalline structure is not often found to exist in the rocks; and even sandstones and conglomerates are more rarely met with than loose sand and water washed beds. The clay occurring here is always amorphous, and limestones sometimes exhibit traces only of crystallization. Calcareous tufa, that loose lime deposit from calcareous water, is here found for the first time. Mineral species are not numerous; they generally consist of arsenical and iron pyrites, while hydrated oxydes of iron and manganese penetrate the rocks, and are sometimes found in separated deposits. The position of the stratification, generally indistinct, is mostly horizontal or basin-shaped, rarely upheaved, this only taking place in the vicinity of abnormal masses. Peat is found in beds of much economical importance.

The task of arranging and classifying tertiary deposits is rendered very difficult, by the fact that they vary so much in different localities; it therefore becomes necessary to have frequent reference to geognostical equivalence in comparing the tertiary of different regions. Special reference must be had to fossil remains, which, while distributed in great number, yet exhibit considerable local variations of form. It will be seen, that during this epoch of the world's history, considerable climatic differences prevailed on the surface of the earth.

The dicotyledonal form of plants prevails in the tertiary, and, while polyps become rarer, mollusca increase so as to form entire beds. Belemnites and ammonites have entirely disappeared; and, on the other hand, insects, fishes, reptiles, and mammalia, with some birds, become very conspicuous. The reptiles assume more familiar forms, and the mammalia are represented by pachyderms, none belonging to recent genera; ruminantia come next; and last of all, carnivora.

These organic remains are generally in much better preservation than in the older formations, from not having been exposed so long to the tooth of time and the accompanying destructive influences.

The views of different geologists with regard to the classification of the tertiary masses vary very much. Some rest it upon the different number and character of the contained fossils, but the method is liable to many sources of error. The arrangement which we shall here adopt is that of Hausmann and Bronn.

Calcaire Grossier, or Coarse Limestone Formation. This formation, which embraces the so-called limestone as a conspicuous member, rests, when in normal situation, directly upon the newest cretaceous strata. The principal rock species are: various limestones, among them the pisolite lime, a ferruginous, coarse limestone, sometimes oolitic and traversed by streaks of clay; a purer, compact, often sandy limestone, which often passes into a true shell conglomerate, a limestone slate, and a silicious limestone (calcaire silicieux) often containing hornstone and chalcedony, and known as *meulière de Paris*, or French buhr stone.

Marls, among them a sandy, argillaceous, marly lime, and marl clay, sometimes assuming a slaty texture. These masses are generally grey,

yellowish, or reddish in color, and bituminous. Adhesive slate is sometimes imbedded in the calcareous marl, as also freestone and some other silicious substances. A compact celestine sometimes occurs. Clay, as potter's clay, marl clay and loam, of which some are important in the arts, as the *Argile plastique* and the *London clay*.

Sand and sandstones, the former predominating, and sometimes marly, sometimes argillaceous or ferruginous. The sandstones exist sometimes as argillaceous, sometimes as marly or ferruginous sandstone; in the latter case they often have a tubular, rough appearance.

Among the subordinated masses belong gypsum beds; among them the Paris bone gypsum. This is sometimes compact, sometimes sparry, and closely mixed with carbonate of lime. In the tertiary deposits gypsum again occurs in marl; also peat and iron-stone.

This calcaire grossier or coarse limestone is highly developed in the Paris basin, and has there been carefully studied, especially by Cuvier and Brogniart. The strata occur in the following order:

Beneath lies the pisolitic limestone (*calcaire pisolitique*), a marine formation, characterized by Corals, Echini, Dentalium, Serpula, Cytherea, Venus, Cardium, Arca, Solen, Natica, Cerithium, Fusus, &c. Cerithium is found in great abundance.

Next comes a plastic clay (*Argile plastique*), whose purer lower bed is separated from the impure upper by a layer of sand. It contains both fresh water and marine shells, as Planorbis, Paludina, Melanopsis, Cyclas, and Ostrea. Also remains of Crocodiles and Chelonia, as the genus *Emys*.

Then follows a purely marine formation, the calcaire grossier proper, whose lower beds are of an arenaceous texture. Upon the limestone mass lies a sandstone of tolerable firmness, much used in Paris for building purposes; on this, again, rest beds of marl and firmer limestone. The lower strata of the calcaire grossier contain nummulites; the middle exhibits a vast number of fossils, the most abundant of which are: of plants—*Equisetum brachyodon, Pinus defrancii, Confervites, Endogenites echinatus, Flabellaria parisiensis, Caulites, Potamophyllum multinervis:* of vertebrata—*Palæotherium, Lophiodon,* and *Chelonia:* of shells—*Milliolites, Cardium obliquum, Lucina saxorum, Ampullaria, Cerithium, Orbitolites plana, Cardita avicularia, Oculites elongata, Alveolites milium, Turritella imbricata, Calyptræa trochiformis, Pectunculus pulvinatus, Cytherœa nitidula* and *elegans, Turritella multisulcata, Ostrea flabellula, Natica epiglottina, Trochus agglutinans, Cerithium cornucopiæ,* &c.

Upon the calcaire grossier rests a silicious lime (*calcaire silicieux de St. Ouen*), in the lower part of which fluviatile and marine shells are found intermixed, while in the upper, fluviatile alone are met with.

Then follows the marl with the bone gypsum, also fresh water formations, as they are filled with Cyclas, Paludina, Planorbis, &c. The bed attains a thickness of 170 feet, and, in addition to the fossils already mentioned, contains likewise fishes and mammalia; of the latter, *Palæotherium, Anoplotherium, Adapis, Didelpnys,* &c. There are also remains of birds, crocodiles, sea and fresh water turtles, &c.

The series is closed by a deposit of sand, sandstones, and marl, of marine origin, and containing Ostrea (*O. flabellula* especially), fishes, &c. In the sand there is found the so-called crystallized sandstone of Fontainebleau, which, however, in reality it is not. It consists of an aggregation of rhombohedrons like those of calcareous spar; in fact, these crystals are only carbonate of lime mixed up with sand. It is a little remarkable that the force of crystallization should have been great enough to overcome these impurities.

The Paris tertiary basin rests upon the cretaceous. *Pl.* 44, *fig.* 6, exhibits a map of it, in which its distribution may be more readily followed. *Fig.* 7 is a section of the same. The line *a* indicates the level of the sea, 1 the tertiary, 2 the cretaceous, and 3 the Jurassic strata.

The London tertiary basin exhibits certain features distinguishing it from that of Paris; while in the latter, limestone masses entered in considerable prominence, in the former, clays and marls predominate. The bone gypsum is entirely wanting. The masses occur in the following order:

Beneath lies a plastic clay very rich in fossils; upon it rests the London clay, a fat clay, with many marly concretions and shells, as well as remains of turtles and crocodiles; then follows the Bagshot sand, a sandy marl, with numerous marine fossils, and a non-fossiliferous sandstone. In the southern part of the English Bagshot sand, in the Isle of Wight, and on the coast of Hampshire, large beds of marine strata alternate with fresh water, consisting of greenish limestone, marls, and sand beds, in which are found remains of reptiles, Anoplotherium, and Palæotherium.

In Provence, in the calcaire grossier, there is found a bed of coal, intermediate between lignite and peat; it contains remains of various insects, especially of the Coleoptera. This formation is known in Germany, occurring here and there in single patches, as in Mecklenburg, near Kressenberg and Sondhofen in Bavaria, and in Mark Brandenburg; also, in France, England, Hungary, Southern Russia, Upper Italy, in North America, and the East Indies.

Molasse, or Upper Tertiary. Quite loose sandy, marly, or argillaceous masses have the preponderance. There are numerous mammalia in great variety, and of known forms. The principal rock species are:

Nagel-fluh, which passes into sandstone and marl.

Sand and sandstones, especially marly, argillaceous, calcareous, and ferruginous, frequently colored by chlorite and mixed with mica. They often contain concretions of lime and hydrated oxyde of iron, and pass into quartz-sandstone and quartz-grit.

Lœss and loam. Lœss is only a very fine well-washed loam, occurring over considerable tracts.

Clay, in the different varieties, as porcelain, potter's, pipe-, marl-clay, &c. Not seldom it is bituminous and aluminous, and contains, as foreign admixtures, iron and arsenical pyrites, sulphur, gypsum, sphærosiderite, celestine, and a granular clay iron-stone.

Marl, as calcareous and argillaceous marl, which are often mixed with

sand and mica. Shells occur in great number. The principal foreign minerals are sulphur, iron pyrites, arsenical pyrites, gypsum, and petroleum.

Limestones, which in general are very subordinate; they are met with as compact, slaty, loose, oolitic, marly, and breccious; as also marly lime, which is often bituminous. Likewise fœtid limestone, silicious limestone, sandy limestone, and a calcareous conglomerate.

Among the true subordinate masses belong gypsum, often in the form of purest alabaster, rock salt, lignite, not unfrequently inclosing amber, mellite, humboldtine, and retinasphaltum. Iron and arsenical pyrites often occur, as also silicified wood; likewise a granular, argillaceous, or sandy iron-stone. Carbonate of manganese or rhodocrosite is occasionally met with.

The metalliferous sands of the molasse are of great importance, the metals being disseminated in the form of fine grains, as of platinum, gold, magnetic iron-stone, titanic iron, chrome iron-stone, tin ore, &c. These are obtained by stirring and washing the sands in the water, when the metallic matters fall to the bottom by reason of their greater specific gravity. Diamonds are sometimes obtained in a similar manner.

This formation is divisible into two groups:

a. Lower Group, or the Marl Formation. The principal mass consists of clay, sand, and marl, among which occur sandstones and fresh water limestones. Fossils exist in this formation, generally similar to those of the present day. There are numerous genera of Pachydermata, or thick-skinned mammalia. Beds of brown coal, of great extent and thickness, are accompanied by clay or sand, or, instead of the latter, by sandstone, converted into quartz grit in the neighborhood of abnormal masses. In these brown coal beds, and especially in the lower portions, upright stems of trees are met with. The brown coal experiences considerable modification in the vicinity of those abnormal masses, generally basalts, which penetrate them. The nearer to the latter, the greater the similarity to stone coal; and at the surface of contact the coal is changed into a lustrous coal, disposed in short columns perpendicular to the abnormal mass. These beds sometimes become inflamed by the oxydation of some of the included mineral substances, and thus exert an igneous action on the rocks with which they are in contact. In this manner the porcelain jasper is produced from clay masses. In the vicinity of the brown coal there sometimes occurs polishing slate, or tripoli, consisting entirely of the shields of infusoria. Leaves and fruits (Phyllites and Baccites), especially of Thuja, Juglans, Salix, Populus, Betula, and Acer, are found in the coal, but are specifically distinct from any of the present epoch. Remains of fishes and reptiles are also embraced in this group.

The region of Mayence furnishes an illustration of local variation in the marl group, a section of which is presented in *pl.* 46, *fig.* 18. Beneath lies a blue marl clay (1); next to this come sea sand and conglomerate, with numerous remains of Cetacea and Plagiostomes; then a brackish-water limestone, or one containing both marine and fluviatile shells, with *Mytilus faujasii* and *Cerithium plicatulum* (2–7); above the whole are sand and sandstone masses, in which lie imbedded numerous remains of terrestrial mammalia.

A curious formation is found at the foot of the Alps, not readily referable to any particular position; it seems rather to belong between the upper and the lower groups. The molasse there lies beneath, with marl and calcareous sandstones predominating; upon this is nagel-fluh of coarse grain, with subordinate beds of marls and sandstones. Then comes a shell sandstone, composed of true sandstone and nagel-fluh, embracing numerous fossil shells.

b. The Lower Group, or the sub-Apennine Formation. Sandstone is of inconsiderable extent, but marl and clay masses, as also pebbles and boulders, rarely combined into solid conglomerates, are abundant. The limestone is principally fresh-water, and in the form of calcareous tufa. Shells are numerous. Of mammalia are found deer, oxen, bears, hyenas, and mastodons; all, however, of extinct species.

Among the primary masses of the sub-Apennine formation belong marls of mostly dark colors, passing into sandstone and slate clay; they embrace celestine, iron pyrites, asphaltum, petroleum, &c.; of sandstones, calcareous, marly, argillaceous, and quartzose sandstones, in the form of pebbles and boulders, sometimes united into conglomerate. Gypsum is subordinate, including the alabaster of Volterra.

As a general thing the marls occupy the lower portion, the sand and pebble masses the upper regions. The marls and sandstones embrace vast numbers of shells, mostly in good preservation; also remains of mammalia, as elephants, rhinoceros, cetacea, &c.

This second group of the Molasse is well called the sub-Apennine group, as it borders the Apennines and forms its outskirts.

In this sub-Apennine formation are to be included the sand and pebble deposits on the south coast of Spain, containing single strata, entirely filled with oysters and pectens. The same strata are met with in Southern France and in England, in which latter country they are known as Norfolk and Suffolk Crag. Here likewise belong sea-sand beds found in patches in various parts of Germany, and also embracing shells. These deposits contain various marls, sandstones, and limestones, in which are subordinated beds of iron-stone and drift.

The thickness of these masses varies considerably; they sometimes form hills and even entire mountains. They not rarely are pierced and overlaid by basalts, which, in many cases, has been the cause of their preservation from the denuding action of the water currents. The occurring fossils are entirely local. The quartz grit sometimes contains leaves of trees and opalized wood. Some of the animal forms are *Corals*, *Nummulites*, *Clypeaster*, *Nucleolites*, *Spatangus*, *Terebratula*, *Ostrea*, *Pecten*, *Pectunculus*, *Venus*, *Solen* (*as S. hausmanni*), *Turritella*, fishes, &c.

The *diluvium* of Buckland belongs under this head. It consists of sand with subordinated clay and earth, sometimes consolidated into rocks of considerable firmness. The argillaceous portions are generally inferior, and upon them are spread out the sandy. There are also isolated sand hills, with various kinds of detritus, as also the drift accumulations of the north, which are of wide extent, reaching even into the river valley of the Elbe

and Weser. These constitute the so-called erratic phenomena. Erratic boulders are often of considerable size, and are generally derived from more northern mountain regions. The petrographical character of the boulder sometimes enables us to decide with tolerable accuracy as to its native locality. In the south of Europe such blocks sometimes occur as the one shown in *pl.* 46, *fig.* 19, from forty to sixty feet in diameter, and found near Monthey in the Pays de Vaud. At this period masses of still more limited occurrence were formed, as a fresh water limestone, calcareous tufa, or older travertine, containing hornstone, jasper, and flint. In it are found *Lymnæa*, *Planorbis*, *Paludina*, *Helix*, *Pupa*, *Cyclostoma*, &c. Volcanic tufas and conglomerates are sometimes associated. Mammalia are represented by proboscidian pachyderms, oxen, and deer. To this same period belong the calcareous conglomerates and osseous breccias, often found elevated at a considerably high level on the southern coast of Spain; also, the *calcaire mediterranien* of Nizza, the clefts filled with shelly conglomerate, and the bone deposits of caverns. The latter are extensively distributed, and occur principally in cavities of limestone rocks, which have been shattered or fissured in some way or other, and the fissures excavated by the action of water or corrosive gases. At the bottom of the caverns there generally occur blocks and bones of various kinds, often cemented by a ferruginous mud and sand, the whole mass covered by stalagmite, stalactites depending from the top and sides. The origin of stalagmites and stalactites has already been explained. The bones are generally broken and crushed, especially the long bones of the extremities. Many in certain localities exhibit traces of carnivorous teeth, as of hyenas, wolves, &c. Some are rounded by the action of water. The cavities of the larger bones will frequently be found to contain fragments of bones belonging to smaller animals. Bone caves generally occur in series of hollows, connected by narrow passages.

Various theories have been propounded as to the manner in which these deposits have been produced, but no single one, nor indeed a combination of all, is sufficient to account for the phenomena which are sometimes presented. Some have been introduced, no doubt, by the agency of rapacious beasts which made dens of the caverns. Thus, in the celebrated cave of Kirkdale in England, unmistakable evidence of this is presented in the fact, that with the bones are associated, in vast quantities, the excrements of hyenas, and the bones themselves are broken and shattered in precisely the same manner as if they had been subjected to the action of hyenas of the present day. The association of water-worn sticks, pebbles, &c., with the bones, also shows that to the action of water may be ascribed a considerable share in the phenomena. Again, many caves are connected with sink-holes or katavothra, funnel-shaped depressions in limestone regions, into which water pours from a greater or less extent of country. Such pits being thickly overgrown with bushes, naturally afford a secure harbor for predaceous animals, which drag their victims into these localities for security. The accumulating and broken bones are carried down into the cavity at the bottom of the pit by the next heavy rain, and thus either

dropped into the subjacent or associated caverns, or accumulated in the narrow galleries of the roof or sides. The richest deposits are frequently found in horizontal or inclined galleries or excavations in the roof of the cave, and under such circumstances as to preclude the possibility of ar introduction through the mouth or main entrance. Such sink-holes may also seem to explain the introduction of certain foreign earth-beds and masses into the cave, as also in some measure the excavation of the cave itself.

Some of the most celebrated bone caves are the Baumann's-cave and Biels-cave in the Hartz, the cavern of Gailenreuth (*pl.* 52, *fig.* 9, in section), and the Wirksworth cave in England (*pl.* 38, *fig.* 68, in vertical section). Among other remains, the complete skeleton of a rhinoceros was found in this cave. Its skull and horn are shown in *pl.* 40, *figs.* 14 and 15. Similar caves are found in other parts of England and Germany, in France, Russia, and in other portions of Europe. Of other parts of the world, Brazil is extraordinarily rich in such caverns. Dr. Lund has investigated nearly 200 of these, and obtained a large number of extinct species. Few bone caves have hitherto been found in North America, although in the abundance of caverns it is exceedingly probable that many are ossiferous. Remains have been found in the Mammoth cave of Kentucky, in a cave of Greenbrier county, Virginia, and in several caves of Cumberland county, Pennsylvania.

It will thus be seen, that our division of the tertiary after Hausmann and Bronn, is into the Calcaire grossier and the Molasse, with their individual deposits. The principal of the other systems of classification is that of Mr. Lyell, adopted by most English and American geologists. Supposing the number of fossil shells in the entire tertiary to be accurately ascertained, that series of strata in which three and a half to five per cent. of the species are identical with living forms, is called the *eocene;* a proportion of about eighteen per cent. of recent species constitutes the *miocene;* thirty-five to fifty, the *older pliocene;* and ninety to ninety-five, the *newer pliocene.* A classification of this character, based upon the proportion in which existing species occur, may and does answer an excellent purpose when all the fossil shells have been studied and ascertained; where this is not the case, any such arrangement must be liable to incessant modification.

Fossils of the Tertiary Period.

The infusoria play a great part in this period of the world's history as well as in the preceding, as immense beds are sometimes entirely composed of the remains of such animals. In the Paris calcaire grossier, beds are found made up of minute shells, known formerly as Milliolites. They are now divided into many genera. These microscopic shells seem to belong to Rhizopoda, whose turns were arranged in an imbricated manner about a longitudinal axis, so that each new turn partly or entirely covered the older.

In *Biloculina* (*B. opposita, pl.* 39, *fig.* 46), the turns lie opposite to each other, and embrace in such a manner, that only two such turns are visible. *Triloculina* exhibits three such turns: *T. communis* (*figs.* 47 and 48). Both are found in the calcaire grossier, as also *Scutellæ*, very flat echini, of discoid shape: *Laganum tenuissimum* (*figs.* 49 and 50). Of shells there are *Voluta dubia* (*pl.* 42, *fig.* 1), *Dentalium striatum* (*fig.* 2), *Venericardia planicosta* (*fig.* 3), *Fusus bulbiformis* (*fig.* 4), *Emarginula reticulata* (*fig.* 5), *Turbo littoreus* (*fig.* 6), *Scalaria foliacea* (*fig.* 7), *Murex tubifer* (*fig.* 8), *Fusus contrarius* (*fig.* 9), *Cypræa avellana* (*fig.* 10), *Trochus agglutinans* (*fig.* 11), and *Pleurotoma exorta* (*fig.* 12). An immense number of fossil fishes is found in a local marl slate of the calcaire grossier on Monte-Bolca in Verona. They are all of extinct marine species, belonging to the Percoids, Chætodonts, Scomberoids, Clupeoids, Sparoids, and Aulostomes. The most peculiar fishes of the southern calcaire grossier are *Acanthonemus filamentosus* (*pl.* 40, *fig.* 1), *Semiophorus velifer* (*fig.* 2), and *Aulostoma bolcense* (*fig.* 3). The reptiles closely resemble those of the present epoch; among them are crocodiles, lizards, snakes, frogs, &c. One of the most interesting is *Andrias scheuchzeri*, whose skeleton, as exhibited in one specimen, is shown in *pl.* 41, *fig.* 24. It is a well known fossil, but derives its celebrity principally from the fact that Scheuchzer described it as a fossil man under the name of homo diluvii testis. It belongs to the Urodelian Batrachians, of which it is the largest known representative, and stands intermediate between the existing *Menopoma* of North America, and the *Megalobatrachus* of Japan. In the fresh water formation are found many articulata, as Coleoptera, Crustacea, Arachnida, &c. (*figs.* 1–10. There are many genera and species of fossil mammalia. One of the most interesting forms is that of *Dinotherium.* Its true place in the zoological system is not well ascertained, some naturalists ranking it with the herbivorous cetacea, others among the mastodons. It formed one of the largest of all terrestrial mammalia; *D. giganteum* (*pl.* 41, *fig.* 29). The most gigantic of all ruminantia is exhibited in the *Sivatherium* (*S. giganteum, pl.* 40, *fig.* 13), whose remains have been found in the Himalayas. The head equalled in size that of the elephant, while the elongation of the nasal bones indicates the existence of a trunk or proboscis. On the forehead stood two short thick horns.

Palæotherium, a link connecting the rhinoceros and tapir, is an interesting form from the calcaire grossier. Several species have been distinguished, the largest equal in height to the horse, although rather stouter (*P. magnum, pl.* 40, *fig.* 18[a] and 18). *Anoplotherium* was not far removed from the latter, whose remains, associated together, are found in the Paris calcaire grossier. It gives no indication of having had an elongated snout. Its formula of dentition is the same as in Palæotherium, with this difference, that the teeth form a continuous series without any interruption, &c. *A. gracile* (*pl.* 41, *fig.* 27). They attained the size of an ass, had a long, thick tail, and were more slightly built than the Palæotheria.

The genus Rhinoceros is found only in the upper tertiary beds. Perfectly well preserved specimens have been found in the ice of Siberia, under

circumstances similar to those already mentioned with respect to the mammoth or priscine elephant. Canines are wanting in the rhinoceros, and of incisors sometimes there are $\frac{2}{2}$, sometimes none. There are several molars on each side of both jaws. *Rhinocerus tichorhinus* is of frequent occurrence (*pl.* 40, *figs.* 14 and 15).

Fossil elephants are very widely diffused, but most abundant in the high north, especially in Siberia: the ivory from this region of country enters largely into trade. Perfect specimens have been obtained from the ice-cliffs, covered with a woolly hair mixed with longer bristles. Their grinders are composed of vertical lamellæ, of dentine, enamel, and cement; and there are but two teeth, sometimes only one, on each side of the jaw. A molar of *Elephas primigenius*, or mammoth, is represented in *pl.* 40, *fig.* 16, from the upper surface

The genus Mastodon, now entirely extinct, exhibits close relations to the elephant, having the same general structure of frame, tusks, proboscis, &c., but differing in the molar teeth. These, to the number of one to four on each side of the jaw, exhibited two rows of mastoid or nipple-shaped protuberances of considerable size along the face of the tooth; these were sometimes united, so as to exhibit a series of transverse high ridges along the tooth. Some individuals possessed tusks of immense size. This genus is represented by several species, the existence of only one of which, on the continent of North America, has been satisfactorily ascertained. This species (*Mastodon giganteus*, *pl.* 40, *fig.* 19, head) is found in various localities, the most celebrated being Big-bone Lick in Kentucky. It has, however, been found in many other States of the Union. The most perfect specimens exist in collections in Cambridge and Boston, as also in Philadelphia, the British Museum, &c.

Armadilloid animals, which at present are only found living in South America, are represented by fossil forms in Europe. Some extinct species of very large size have also been found in the sands near Buenos Ayres, as *Glyptodon clavipes*, six feet long (*pl.* 40, *fig.* 11[a]). This possessed an armor composed of hexagonal pieces; as also other anatomical peculiarities distinguishing it from its allies.

Megatherium, found in various parts of North and South America, is represented, perhaps, by but a single species, *M. cuvieri*. *Pl.* 40, *fig.* 20[a], is a figure of a skeleton sent to Madrid from Buenos Ayres. This animal was of a clumsy build, having a great similarity in the form of the skull to the sloth. It occupied a position in point of size between the elephant and the rhinoceros. It had neither incisor nor canine teeth, but 18 molars. Its mode of life must have been somewhat similar to that of the sloth, although probably not arboreal. It seems rather to have procured its food (twigs and leaves) by uprooting trees, which it was well capable of doing by means of its sharp claws, immense straight and thick broad tail, &c. *Pl.* 40, *fig.* 20[b], is a supposed restoration of the animal.

Mylodon was not unlike Megatherium in general character, and is represented by three species. A complete skeleton was found in the sands of the Rio de la Plata, not far from Buenos Ayres; it is about eleven feet

long, and is preserved in the Museum of the London Royal College of Surgeons: *Mylodon robustus* (*fig.* 21). The other two species are *M. darwini*, from Brazil, and *M. missouriense*, from various parts of North America.

The diluvial Felidæ or cats, judging from their remains, must have been of terrific rapacity. The entire framework of many of these animals indicates a power entirely sufficient to compete with the gigantic forms by which they were surrounded. In strength of frame, if not in actual size, some of these exceeded the largest lions and tigers of the present day. *Smilodon populator*, from Brazil, is an extraordinary form, more nearly allied to the hyenas, however, than to the true cats (*pl.* 40, *fig.* 17). A scull of *Hyæna spelæa* is shown in *pl.* 41, *fig.* 33, and of *Ursus spelæus* in *fig.* 34. *Fig.* 28 represents a skeleton of the gigantic fossil Irish elk, *Megaceros hibernicus*. We may remark that the majority of remains from the European bone caves belonged to deer, bears, hyenas, &c.

The existence of fossil Quadrumana in the European tertiary, although at one time doubted, is now beyond any question. *Pl.* 40, *fig.* 22, represents the lower jaw of *Pithecus antiquus*, a species found both in Southern France and in England.

Pls. 39 and 41 contain representations of two animals prominent among the fossil Mammalia of North America. *Pl.* 41, *fig.* 30, represents a large specimen of *Mastodon giganteus* from Missouri, as mounted by Koch, and by him called *Missourium theristocaulodon* (or *tetracaulodon*). In mounting the skeleton the discoverer erroneously made the tusks turn too much outward. Their true position is as in the elephant of the present day. The original specimen was purchased by the British Museum, and reconstructed by Professor Owen.

Pl. 39, *fig.* 51, represents a skeleton of a fossil cetacean from the rotten limestone of Alabama, as incorrectly restored by its discoverer, Koch. It is the same as was exhibited in the United States and Europe as *Hydrarchos harlani*, or *sillimanni*, and erroneously supposed to be an Enaliosaurian of gigantic size, allied to Ichthyosaurus and Plesiosaurus. It is now well known to be one of the cetacean Mammalia, and bears the name of Basilosaurus, given to it by the first describer, Harlan. It has also received the names of Zeuglodon, Phocodon, Dorudon, and Squalodon. Several species are now known from the American tertiary, and similar remains occur in the eocene of France, south of Bordeaux. It must not be understood that the skeleton we represent was found in its present connexion, or even belonged to the same individual; it is such a restoration from different individuals as we are entitled to make when the proper caution has been observed. We have already referred, however, to the inaccuracy of our figure.

Figs. 58 and 59 represent fragments of the head; *fig.* 66 is an ideal restoration of the entire head; the other figures represent different portions, as ribs, vertebræ, phalanges, portions of the head, &c. The highly characteristic teeth are shown in *figs.* 60 and 61.

Top Series.

The top series embrace the masses known as *Alluvium*, and which are even now in process of formation. The term includes both normal and abnormal masses, the former containing remains of animals and plants that still exist, even including man and his works of art. A portion of the alluvium belongs to the prehistoric period; the rest has been formed either before our own eyes or those of our ancestors. Alluvium is divided by Hausmann as follows:

A. *Masses which have experienced no Great Change of Position*

Under this head belong:

a. **Beds Formed under the Influence of the Sea,** such as accumulations of shells with sand and gravel, which gradually unite into a solid shell conglomerate, and often lie at a not inconsiderable height above the present level of the sea.

b. **Newest Marine Limestone, of Varying Degrees of Compactness and Solidity.** It is generally of a light color, sometimes colored brown by oxyde of iron. It contains numerous remains of marine animals, very rarely human bones: *pl.* 41, *fig.* 36 shows a human skeleton from Guadaloupe.

c. **Coral Reefs,** which, partly destroyed, are converted into conglomerate, and are no longer inhabited. They frequently have an annular shape, and form the atolls or coral islands, of which so many occur in the Pacific ocean (*pl.* 49, *fig* 2).

d. **Newest Marine Sandstone,** produced by the cementation of littoral sand by lime or oxyde of iron. Its colors are white, grey, or red; and the formation exists well developed in the straits between Italy and Sicily. It frequently includes remains of marine shells.

B. *Formations produced under the Influence of Running or of Standing Water.*

a. **Traventine, or Newer Calcareous Tufa.** It either forms the bottom of pristine lakes or ponds, or is deposited in the vicinity of springs or waterfalls. This latter is the case in the cascade of Teverone near Tivoli (*pl.* 52, *fig.* 5). The traventine sometimes overlies peat, and is covered by loam; sometimes it lies on older masses, in which case the strata may occupy a rather high level. They are generally accompanied by oxydes of iron and manganese, and are sometimes bituminous. Fossils are very numerous in single portions, and generally of still living forms, as Helix, Planorbis, &c., among shells. Stems of grass, leaves, moss, &c., contribute not a little to the porosity of the rock. Bones of mammalia, as

of deer, oxen, &c., with their tracks, are met with; as also the products of human industry.

b. **Silicious Tufa,** a deposit from hot silicious springs. It forms either conical hills on whose summit the spring is generally revealed, or else the filling up of cavities, as in the crater of the great Geyser of Iceland (*pl.* 44, *fig.* 17).

c. **Soda and Salt,** which are sometimes deposited on the edges of lakes.

d. **Deposits of Borax** (boracic acid).

e. **Deposits of Alum and Magnesia.**

f. **Beds of oxyde of Iron,** on the bottom of lakes.

C. *Masses which have arisen directly from the Decomposition or Destruction of Rocks.*

a. **Piles of loose blocks,** occurring on the sides of mountains, and sometimes covered with soil, in which case they may give rise to the phenomena of land slides.

b. **Gravel Beds,** produced by the weathering of rocks. Thus we have granite, gravel, syenite-gravel, &c. These gravels are sometimes cemented anew, and produce the so-called regenerated granite or syenite, and granitic conglomerate.

c. **Earthy Masses** produced from the subjacent rocks, and occupying their original position.

d. **Masses produced by the Decomposition of Plants,** among which peat stands pre-eminent. We distinguish wood, leaf, and moss peat, according as one or other of these substances contributed principally to the formation of the peat bog. The deposits generally occur in depressions, yet sometimes in elevated places. Their origin presupposes a water-tight soil, such as is produced in particular by clay and granitic gravel. The beds vary in extent and thickness, the latter being greater in the middle than on the borders, as would naturally result from a deposit in a trough or basin.

Peat often includes mineral bodies, among which may be mentioned pyrites, gypsum, yellow and brown iron-stone, limonite, phosphate of iron, and retinasphaltum. The distinction is made into green and black moss, according as the moor is overgrown with vegetation or not; another distinction may be made into peat from marine and from fresh water plants.

e. **Masses produced by Animal Agencies.** Here belong the beds of silicious meal, which are really aggregations of infusorial shells, mixed with the pollen of pines, &c. Here also are to be ranged those deposits of guano occurring on the coast of Patagonia, Peru, &c.

D Masses which have Experienced a Change of Original Situation.

Here belong.

a. **Glacier Walls, or Moraines,** blocks of rock heaped up by the movement of glaciers.

b. **Masses in River Beds,** carried along and spread out at the mouth of the stream, so as to form a delta.

c. **Masses Washed from the Banks of Rivers,** and finally spread out on the bottom of the sea.

d. **Dunes or Heaps of Sand,** piled up on the shores of seas by the action of waves and storms, and carried landwards. They slope gently towards the sea, and fall away abruptly towards the land (*pl.* 44, *fig.* 8).

E. Common Earth.

This constitutes the external crust of the upper series and the tillable soil. This is either rendered so by human industry, or is a purely natural product, as in the primitive forest, where it is produced by the fall and decomposition of vegetable matter. (*Pl.* 51, *fig.* 1, represents a primitive forest of Brazil.) The proportion of humus in soil is very variable, sometimes more and sometimes less. It plays an extensive part in respect to the nutrition of plants, both on account of its decomposition in carbonic acid and water, by the action of the oxygen of the atmosphere, and of its porosity, which facilitates a condensation, and even a chemical transformation of gases, ammonia in particular.

Springs and Artesian Wells.

Before passing to the consideration of abnormal masses, it may be proper to premise a few general remarks respecting springs.

It is a well known circumstance that vapors constantly ascend from seas, lakes, streams, &c., which are condensed in the higher regions of the atmosphere, according to physical laws, and there forming clouds, are again precipitated to the earth in the form of rain, snow, hail, &c. It is the process of distillation on a large scale that provides the dry land with water, which presents itself either in the form of springs or subterranean currents. The masses with which we have become acquainted in our study of normal rocks, are, as we have seen, of a higher or lower degree of density, and are capable of taking up a less or a greater quantity of water. This water passes naturally from the higher to lower levels, and emerges at the latter in the form of springs, or else it continues subterraneously to neighboring lakes, seas, or other bodies of water. Many springs are exhibited in caverns or mines, as in the Dunold Mill Cave, near Kellet in Lancashire, where the walls are clothed with deposited limestone (*pl.* 53, *fig.* 2) The springs may be of various kinds of origin; thus a

hole sunk near the bank of a river may lead to a stratum saturated by lateral absorption from the running water in the bed of the stream; they may be produced by the emergence of brooks and other streams, after disappearing in the earth; by lakes at high elevations; by the melting of snow and ice in glacier masses, from which the water emerges in a stream (*pl.* 49, *fig.* 5, the Rheinwald glacier, where the water emerges in several places); they may also arise when an inferior stratum in a series is water-tight, and the rain falling on the earth sinks to this stratum, and passes along its upper face until it meets with a suitable outlet, either natural or artificial. This latter kind is of especial interest, as permitting the construction of *Artesian wells*. An Artesian well can only exist when the water which is to supply it collects between basin-shaped strata. *Pl.* 48, *fig.* 2, illustrates the conditions necessary to the production of an Artesian well; the water, draining from a considerable elevation and extent of surface, sinks into basin-shaped strata, and there accumulates by coming between strata impervious to water. A pressure will thus be exerted upon any point of the inclosing walls, equal to that of a column of water, whose height is the vertical height of the most elevated portion of the layer of water above the point in question. If, then, the interspace, *a*, between two impervious strata be reached by means of a hole bored through the incumbent masses, the water may flow out through the hole, and be carried by hydrostatic pressure to a height *b*, equal to that of *a*. If a tube be inserted in the hole, the elevation of the ascending stream will be modified by the resistance of the air and the friction on the walls of the tube; thus the actual height of the water in the tube will be less than that which is theoretically possible.

On boring at a point, *d*, lying higher than the body of water, *c*, the water will only partially fill the tube, that is, to the level of *c*.

The boring of Artesian wells is attended with many difficulties, as it requires an accurate knowledge of the geognostical character of the country to make success anything more than problematical. And even if success be theoretically certain, unknown and local conditions may exist in the subjacent strata to render such success impossible. Boring instruments of different character are required for different kinds of rocks or deposits, and the peculiarities of the particular case may be such as to require a highly inventive genius to suggest new apparatus suitable to the emergency in question, when all the old appliances have failed. The principal kinds of boring tools are those intended to penetrate masses of slight consistence, as in *fig.* 11; those intended to elevate watery, muddy, or pasty masses from the bottom of the cavity, as in *fig.* 12, consisting of a cylinder provided with a valve, so that substances may enter, but cannot pass out again without assistance; finally, those intended to penetrate hard rocks, and for this purpose provided with sharp corners (*figs.* 6 and 7). These instruments are screwed to strong shafts or attached by iron pins, and set in vertical and rotary motion by various forms of machinery, this being effected in a specially contrived house or shed. *Fig.* 4 represents the interior of such a boring shed. The hole must be lined with tubing, to

prevent a filling up by pieces of rocks, gravel, or other substance, which might slip in from the side. These tubes are adjusted in their place by means of the borer, 14. The instrument, 5, is employed to extract the tubes again, by screwing into them and thus elevating them from the cavity. It sometimes occurs, that the shafts to which the borers are attached, break off in the hole; in this case, the instrument, 9, is employed, which, being screwed around the upper end of the broken shaft, takes firm hold of it. The other borers, 8, 10, 13, and 1–30 of the boring shed are used in particular cases.

One of the most important and interesting Artesian wells ever constructed is that of Grenelle, near Paris, in which, for eight years, the operation was continued, and which was sunk to a depth of 1961 feet below the ground, or 1696 below the level of the sea, thus nearly four times as deep as the elevation of the cathedral of Strasburg. (See *fig.* 3.) According to the report of the engineer, M. Mulot, who directed the boring, the geological peculiarities of the strata passed through, were as follows:

1. Alluvial masses to the depth of twenty-seven feet.

2. Argile plastique, with muschelkalk, quartzose and argillaceous sand, variegated clay, &c., to the depth of about 173 feet.

3. White chalk, with beds of dolomite and silex, to the depth of 910 feet.

4. Compact grey chalk, with silex here and there in the upper portion, extending to a depth of 1480 feet.

5. Chalky Glauconia strata to the depth of 1666 feet.

6. The gault, with iron pyrites, phosphate of lime, and fossil remains in the upper portion; green and white sand occurring in the lower and middle strata.

Although some geologists have ascribed to subterranean lakes the origin of the water emerging from Artesian wells, there are many circumstances that conclusively prove that, in most cases at least, these waters are entirely of immediate atmospheric origin. An Artesian well at Tours, on the Loire, brought up remains of plants and shells from the calcaire grossier, the origin of which could be pronounced upon with all confidence. The plants were of such a character and appearance as that they could not have been in the water for more than three or four months. Other Artesian wells, as those at Elbeuf, Bochum, &c., have occasionally thrown up eels, groundlings, and other animals.

Pl. 48, *fig.* 1 is intended to furnish a coup d'œil of the normal masses. The abnormal masses have been considered as the oldest, for the sake of separating them from the normal.

A. 17. **Abnormal masses,**	strata	1—4
B. **Normal masses,** viz.:		
16–11. Primary or bottom series,	"	5–16
10. Transition slate system,	"	17, 18
9, 8. Carboniferous system,	"	19–22
r–o. Kupferschiefer formation,	"	23–26

n, m.	Rock salt, or saliferous formation,	strata 27, 28
l–g.	Jura formation,	" 29–33
f—a.	Cretaceous,	" 34–38
6–3.	Tertiary masses,	" 39–61
2, 1.	Upper series,	" *a–e*

Influence of Water upon Rocks.

Water exerts a very great influence upon the masses composing the earth's crust. Water descending from the clouds in the form of rain, naturally contains such substances as are floating in the atmosphere; among these are carbonic acid, traces of ammonia, and, under certain circumstances, very slight traces of sulphuric acid. The inorganic particles originally contained by water are deposited or separated from it in its evaporation. When the water again descends, it not only retains its original inherent property of dissolving and disorganizing portions of rock, but will be found to have derived additional power in this respect from the carbonic acid. Water by itself, or chemically pure, is incapable of dissolving carbonate of lime, but after obtaining carbonic acid from the atmosphere, and still more from the humous particles of the soil, it can effect this solution in considerable quantity. The portions of lime taken up are generally deposited in fissures, veins, caves, druses, &c., in the form of calcareous spar, stalactites, &c. The chemical effect of the carbonic acid is to form a soluble bicarbonate of lime with the original carbonate of the limestone. Similar influences may be exerted upon other masses besides limestone, so that a gradual destruction of all rocks is taking place with greater or less rapidity. The greatest mountains will, then, in time, be completely dissolved, like sugar in water. Rain water, while thus decomposing rocks chemically, and disintegrating them mechanically, acts upon them afresh in transporting them towards the ocean or still lakes, where they are again deposited in the form of strata. The natural tendency of things, then, is to elevate the valleys and low regions, and depress the elevated, and so to reduce all to the same level, or to the regular spheroidal solid. Another mode in which the destruction of rocks is effected is by the force of waves and currents. The breakers of the sea, dashing with irresistible force upon the rock-bound shore, shatter the rocks, and breaking them into blocks of various size, spread them upon the bottom. Wherever, then, the coast is lined with rocks, these generally are fissured, cleft, or otherwise affected so as to be exhibited in every variety of form. Innumerable instances might be adduced. We shall only refer to the curious serpentine rocks on the coast of Cornwall, in the bay of Mullian, not far from Lizard Point (*pl.* 53, *fig.* 7), and the rock groups on the Faroe Islands (*pl.* 49, *fig.* 3).

The force of waves not rarely results in the production of caves, some of them of considerable dimensions. Among these may be mentioned Fingal's cave on the Isle of Staffa, inclosed by the most beautifully symmetrical columns of basalt (*pl.* 52, *fig.* 6); the fresh-water cave (*pl.* 51, *fig.* 4),

and Blackgang cave (*fig.* 5) on the Isle of Wight; and the peculiar arch of rock on Cape Parry, in the arctic regions (*fig.* 3). Similar formations occur in the case of fresh water streams and lakes.

Waterfalls, too, in particular cases, produce striking results. Thus the entire body of water in Lake Erie, in pouring into Lake Ontario, dashes over a precipice of about 160 feet in height. The rock wall over which the water pours is continually undermined by the impact of 670,000 tons of water in every minute falling from the top, and the upper portion crumbles gradually away, so that the falling mass constantly recedes in position. At some future day the recession may extend to Lake Erie, and the result may be the draining of the lake itself, or even of the entire lake series, thus adding nearly 72,930 square miles to the land surface; a cataclysm of no ordinary magnitude when, in addition to the above result, we consider the effect which must be produced by the impetuous bursting of all their barriers by the waters in the descent to the sea. *Pl.* 50, *fig.* 8, represents the Niagara Falls from the American side. Similar phenomena are presented by the Dal-Elf-Fall near Elfkarleby in Sweden (*fig.* 9), as also by the Rhonetrichter near Bellegarde in the French department de l' Ain (*pl.* 53, *fig.* 6). Streams of water sometimes often pierce rocks and form great gateways, over which pass the so-called natural bridges, constituted by the portion remaining. A remarkable instance of this is to be found in the valley of Icomonzo in Columbia (*pl.* 49, *fig.* 4). The natural bridge near Lexington, Virginia, is another illustration.

Water in the form of ice often produces great disturbing effects, and, indeed, has every title to being considered as a rock species. The descent of large glacier masses to the edge of the sea, and their accumulation along the shore, give rise to Icebergs, which are sometimes very dangerous to navigation, both in their original locality and in more tropical regions, to which they are carried by ocean currents or winds. It is to glaciers and icebergs that many of the phenomena of diluvial scratches, transportation of boulders and rocks, &c., are ascribed. *Pl.* 52, *fig.* 1, is a view of icebergs and ice-cliffs in the antarctic regions.

ABNORMAL ROCK MASSES.

Abnormal masses are essentially different from the normal, in standing in regular order of succession neither to the latter nor to each other. They pierce through the normal rocks in the most diversified directions, and traverse them just as they traverse each other. In this interpenetration of each other by abnormal masses, it is possible to decide in many cases as to the relative ages; but the determination is always more difficult than in the case of normal rocks, and the same species may in one region be older, and in another younger, than those with which it is associated. This relation is beautifully exhibited by granite, which was considered by the older geologists to be the most ancient of all rocks. This supposition is most certainly true in many cases, yet granite is known more recent than the

cretaceous system. Granite is frequently met with that has been traversed by newer granite; then if we find that the older of these granites is more recent than, for instance, the variegated sandstone, the newer must be still more recent. In many cases, however, it cannot be determined whether it be newer than the Muschelkalk, Keuper, Jura, or chalk, which are supported by the variegated sandstone.

Where abnormal masses come in contact with normal, so that the latter are traversed by the former, changes are generally produced, as well with respect to the extensive as the intensive peculiarities of the latter. The changes of external character have reference to the position of the strata, which may be elevated, upheaved, displaced, broken, or even inverted; those of internal character relate to alterations in the petrographical character of the rocks, as the chemical constitution and the condition of aggregation. Sometimes abnormal masses, in penetrating normal, take up a position between the strata of the latter, and thus acquire a pseudo-stratification which it may require considerable acuteness to detect.

Masses often occur which can be referred neither to normal nor abnormal: they owe to the latter their origin, and have been stratified by water; such are various conglomerates, as basalt, trachyte, leucitophyr, and other conglomerates, &c. In general, abnormal masses belong to the isonomic division; they occasionally are heteronomic, in being accompanied by rocks of the latter character. They are always crystalline, and where this is not evident in the fresh fracture, the weathered surface will frequently exhibit it. A glassy texture is highly characteristic of an igneous origin; where this is not exhibited, other phenomena may lead to the same conclusion.

The mineral substances composing the abnormal masses are principally silicates, or compounds of silicic acid. Among these may be mentioned feldspar, mica, pyroxene, and amphibole. Pure silicic acid in the form of quartz is of rarer occurrence as an essential component, and that only in the older masses. Oxydes of iron occupy a conspicuous place, these making their appearance in the more recent abnormal rocks, in proportion as the silicic acid disappears.

The whole character of abnormal masses is opposed to their possession of organic remains. Haussman has distinguished three orders according to the relative ages, as far as this can be ascertained.

1. Plutonic Rocks.

Plutonic rocks are embraced within the region of the primary or bottom and middle series, and are the cause of many of the changes to which these have been subjected. The principal rock species are granite, syenite, eurite, and other porphyries; amphibolic rocks, especially greenstone; pyroxenes, as euphotide, gabase, trap, serpentine, &c. They are not found in definite succession, and the same species often belongs to different formations.

A. *Granite Rocks.*

Granite has often permanent characters over considerable extents. It everywhere exhibits the same grain, the same color, &c.; on its confines, however, variations are sometimes met with; it becomes porphyritic, incloses foreign minerals, among which are schorl and pistacite (thallite), exhibits a weathered exterior, and is often colored red by oxyde of iron. Granite frequently forms masses of great extent, as the Riesengebirge and Erzgebirge of central Europe, and sometimes occurs in a more isolated condition, as in the Brocken of the Hartz. It sometimes penetrates in between abnormal masses, as of gneiss, and frequently forms veins both in normal and abnormal rocks. It not unfrequently happens that granite is traversed by a newer granite; this has then, in most cases, a coarser grain and a different color from the old. The cleavage of granite is frequently very decidedly parallelopipedal, being most clearly exhibited in weathering, where the blocks present an appearance not dissimilar to a sack of wool. These blocks are sometimes tabular, as also globular, and combined with a concentrically scaly cleavage (on the Rehberg in the Hartz). The rock faces of granite are exceedingly picturesque and imposing when the mass is of great amount. The valleys then appear like deep fissures, with the sides presenting a most magnificent appearance. The mountain forms are most generally spherical in outline, with the above-mentioned bag-like rocks strewn around in every direction on the summits; needles and peaks are sometimes exhibited under similar circumstances.

Granite, upon the whole, is very rich in veins, the contents of which are very various. Some contain mineral substances resembling one or more of the natural constituents, as feldspar and quartz; some, again, are occupied by a newer granite, by syenite, porphyry, greenstone, trap, and basalt. Foreign substances are frequently met with in these veins, as dumb veins (these without metallic ores) filled with barytes and fluor spar; or veins, with gold inclosed in quartz or masked by sulphuret of iron; silver and silver ores, with galena, specular iron, hæmatite, oxyde of manganese and tinstone, tungsten, apatite, mispickel, &c. These veins not seldom extend into normal masses, or are found at the confines of the two.

The weathering of granite is very noteworthy, and furnishes products of great importance both to agriculture and the arts. The feldspar, for instance, is decomposed by the continuous influence of the atmosphere, of carbonic acid, and of water. The crystalline portions are clothed with a loose, soft, opake, dull crust, which sinks deeper and deeper, gradually transforming the entire feldspar. The increasing volume exerts a mechanical influence on the granite in crumbling it to pieces, this taking place first at the sharp corners and edges of the cleavage, and subsequently penetrating still deeper. The feldspar thus affected, will, on examination, be found to have been partially converted into a bisilicate of potassa, by the combination of an additional quantity of silicic acid from the quartz; the bisilicate is more readily soluble in water. The alumina, with the diminished amount

of silex, and a proportion of water, remain behind, and form a white, fine-grained, unctuous mass, kaolin, which is an important ingredient in pottery. The soluble silicate of potassa furnishes the potassa so necessary to the plant, and is represented by the formula $\dot{K}^3\ \ddot{Si}^8$, while the aluminous silicate $= \ddot{Al}^3\ \ddot{Si}^4 + 6\ \dot{H}$. All feldspathic rocks experience the same action, as weiss-stein, gneiss, syenite, some feldspathic porphyries, &c. The magnetic polarity of some granitic rocks is somewhat remarkable. The observation was first made at Ilsenstein in the Hartz, subsequently on the Schnarcherklippe, also in the Hartz. Granite occurs in many different periods of normal deposits. In Sweden it is older than the transition slate, which is shown from the fact that it had upheaved the gneiss, and become melted into it, and that then the transition slate rocks were deposited in horizontal nonconformable strata. The granite of Esterelle in Provence is older than the red sandstone. In Sweden, some granites are younger than the transition slates; they have broken through the old red sandstone and overlie it. There are granites in England which are newer than the carboniferous, but older than the new red sandstone. In the Alps, granites overlie the Jura, and, in the Pyrenees, have broken through the cretaceous. The granite is often traversed by other plutonic rocks, as by syenite, eurite, porphyry, and trap; it often itself traverses syenite and various pyroxenes.

The phenomena accompanying the presence of granite clearly testify to its plutonic origin. Masses in its vicinity are generally of greater density than those further removed; grauwacke is changed into hornfels, clay slate into silicious slate, and sandstone into quartz rock. The relation borne by hornfels to granite is frequently very interesting. The former often constitutes a thin covering for the latter, inclosing it in an envelope. Again, it sometimes constitutes a cap to the granite. This is well seen on the Achtermanns heights in the Hartz. Not far from there, on the Rehberg cliff, the granite has passed in veins into hornfels. Sometimes single fragments of the granite are inclosed by hornfels, and the reverse; and if pieces of limestone are present, they are changed into marble. Granite is most extensively distributed: it forms a constituent of almost all mountains throughout the entire earth. Exceptions to the general rule do, however, occur, as it is not found in the Sierra Nevada and the Jura chain.

B. *Syenite Rock.*

Syenite, although small in quantity in proportion to granite, yet stands in precise relation to it. It is frequently found in connexion with normal masses, and only rarely occurs isolated. When in considerable quantity, it is generally shattered, furrowed by deep valleys, whose sides are studded with rocks. The rock features of syenite are much like those of granite; the cleavage also is similar, although less regular.

Syenite is not unfrequently traversed by veins of newer syenite, of different petrographical character. In these veins, again, are sometimes found other veins of very interesting minerals, as elæolite, beryl, pyrochlore,

and polymygnite. There are also veins of trap, dumb veins, and ore veins with gold and platinum, brown iron-stone, and quartz.

The weathering of feldspar in syenite proceeds much in the same manner as in granite. The hornblende resists the decomposition longest, and thus gives rise to a roughness of the stone. Even this substance, however, is forced to yield in time to chemical forces, and a dark ferruginous soil is the result, as favorable to vegetation as that from granite.

Syenite most frequently occurs in feldspathiferous pseudo-strata of the bottom series, as in gneiss. It is also found in nests and veins in the transition slate. Syenite has been met with of more recent origin than the oolite and chalk.

In its other relations syenite is very similar to granite, especially in the accompanying phenomena. The distribution is much more limited than that of granite. It is found principally in Sweden, Norway, Finland, Germany, France, on Mount Sinai, in Greenland, in South and North America, and in some other parts of the earth.

C. *Porphyry Rocks.*

Under this head belong porphyries of various kinds. The principal are: eurite-porphyry, claystone-porphyry, and silicious porphyry. They have generally parallelopipedal cleavage, although both columnar and globular forms occur. Quartz is often separated in a pure state; which, however, is not the case on the newer porphyries, from which, then, they are sometimes distinguished as quartziferous porphyry. Porphyry rocks generally resist well the action of the atmosphere. The mountains present themselves sometimes as sharp combs, acute pyramids or cones; sometimes as high dome-shaped elevations (porphyry mountain near Kreuznach, *pl.* 53, *fig.* 4), with a greater or less quantity of loose rocks and stones about the base.

The internal uniformity of porphyry masses is sometimes interrupted by nests or beds of kaolin or magnetic iron-stone. Veins are not of frequent occurrence. They are stanniferous, ferriferous, manganiferous, plumbiferous, argentiferous, &c., with various gangues.

Eurite-, clay-, and hornstone-porphyry, both in the bottom series and in the transition slate, occur in nests, veins, and beds between the strata; the formation most frequently consists of porphyry that is younger than the carboniferous, but older than the zechstein. The occurrence of porphyry younger than the variegated sandstone has not yet been satisfactorily indicated.

A porphyritic breccia sometimes presents itself as a product of attrition, connected with the elevation of these abnormal masses. The contiguous rocks are shattered, and the pieces cemented together by an earthy mass, the result of the consequent grinding together of the rocks.

The porphyries already adduced are found in prominent positions on the Scandinavian peninsula, in Great Britain, Germany, France, the Altai Mountains, Mount Sinai, and in various parts of America.

In Germany it occurs in the Hartz, in Westphalia, in the trans-Rhenish Palatinate, in the Odenwald, the Schwarzwald, in Saxony, Silesia, &c.

D. *Amphibolic Rocks.*

Of these, diorite is the most conspicuous. It forms veins rather than independent masses. Where it occurs of greater extent, it exhibits rough mountain forms, a character conspicuously impressed upon the individual rocks. This, as in syenite, is caused by the decomposition of the feldspathic substance, most generally albite, thus leaving the harder hornblende in the form of projecting asperities.

E. *Pyroxene Rocks.*

These form both single smaller block masses, and entire connected series of mountains, as also veins and injected pseudo-morphous strata between normal strata; they also constitute caps extending over other rocks. The cleavage takes place in various ways; in curved surfaces, in acute angled parallelopipedons and in columns, which latter often exhibit a striking similarity to those of basalt, and are especially peculiar to trap. The curved surfaces frequently exhibited by diabase are often globular, with concentric scaly lamination. Diabase of this character is not unfrequently called ball rock.

A particular modification of diabase, the shell-stone, has often a stratiform appearance, or pseudo-stratification. The external features of the pyroxenes have many peculiarities. Where they form large masses, the mountains present steep declivities, studded with rugged rocks; where they are surrounded by normal masses, the single portions project in a dome form from them. Diabase amygdaloid is intimately connected with compact diabase, and gradually passes into it; the amygdaloid occurs especially in the external portions of the rock, the compact occupying the nucleus.

Veins of no inconsiderable importance traverse the pyroxenes, containing hæmatite, specular iron, quartz, chalcedony, &c. The trap, trap porphyry, and trap amygdaloid, exhibit veins in which manganese minerals occur with barytes, calcareous spar, and arragonite. Copper and selenium ores are found in veins between diabase and the transition slate, at Lerbach, Tilkerode, and Zorge, in the Hartz.

The pyroxene rocks are not readily weathered, but form, in time, a tolerably good ferruginous soil. The rocks most frequently penetrate the strata of the transition slate, and of the bottom series. The most trap, trap porphyry, and trap amygdaloids, as also some euphotides, are newer than the carboniferous formation, in overlying the limestones of the latter. Some plutonic pyroxenes appear to be newer than the variegated sandstone. Of other masses, it penetrates syenite, granite, eurite-porphyry and allied rocks, and is often traversed by granite.

Among accessory phenomena may be cited the occurrence of breccias, of oxyde of iron, of silicious rocks, as hornstone, whet and silicious slate, which often, injected into limestone, give to it the appearance of marble; also, the occurrence of gypsum in the vicinity of diabase.

Pyroxene rocks are of very general distribution; they are found in Sweden, Norway, Great Britain, Germany, in the Pyrenees, France, south coast of Spain, in the Apennines, and in North America.

Among these masses are also to be enumerated schiller spar, ophite, and serpentine. Ophite, in particular, occurs where serpentine stands in connexion with marble or dolomite. Serpentine is extensively distributed in Turkey, where it has many external features in common with euphotide.

Serpentine is exceedingly interesting, from the mineral substances which it incloses. Among these are chromate of iron, used in the preparation of the pigments of chrome: also, platinum, pyrites, masses of asbestos, broncite, picrolite, chalcedony, opal, &c.

The weathering of serpentine proceeds very slowly, but is much facilitated by the dissemination of iron pyrites. The resulting sulphuric acid combines with a portion of the magnesia contained in the serpentine, and forms sulphate of magnesia or epsom salts.

2. Volcanoid Rocks.

The volcanoid masses coincide more with the volcanic than with the plutonic: they are intermediate between the two, and traverse the latter, but are never pierced by them. The pyrotypic character is very distinctly impressed on them, and while pure silex diminishes in quantity, oxyde of iron occurs in so much greater proportion. The principal rock species are trachyte, phonolite (clinkstone), and basalt.

A. *Trachyte.*

This is often accompanied by subordinate masses of pearl, pitch, and pumice-stone and obsidian, as also by hornstone and claystone-porphyry, and possesses very striking mountain forms, of a bell shape, or that of a cone either acute or truncated. Trachytic rocks lie either in linear series one after another, or they are grouped concentrically. They sometimes attain a considerable height, as the Mont d'Or in Auvergne. Its absolute height is 3000 feet, and the entire elevation above the level of the sea 5800 feet. The cleavage is sometimes conformable to the mountain outline; often, however, columnar or bench formed, as on the Wolkenburg in the Siebengebirge (*pl.* 49, *fig.* 6).

The veins of trachyte are often of importance; some of them contain gold and silver.

Trachyte masses emerge in the most different normal formations; they

are known in the transition slate, and some are known more recent than the chalk and the newest tertiary formations. In Auvergne they traverse granite, and in other countries phonolite and basalt, with which they not rarely exhibit unmistakable indications of a common origin and time of occurrence.

B. *Phonolite (Clinkstone).*

This is intermediate between trachyte and basalt, and is, in most cases, presented as clinkstone-porphyry. It forms a great part of the Rhone mountain, where it is exhibited in forms similar to those of basalt, namely, in spherical masses, or in caps extending over other rocks. Its cleavages are generally flat and tabular, although columns likewise occur. The principal accompanying mineral substances are zeolites.

Phonolite forms greater or less masses in Höhgau, in Bohemia, in the Rhöngebirge (in Thuringia), in the Siebengebirge, and in France

C. *Basalt.*

This embraces true basalt, basalt amygdaloid, anamesite, dolerite, and basalt conglomerate, which, as modifications of one and the same rock, pass insensibly one into the other. Basalt occupies the most important place among the volcanoid rocks; its mountains may not be so high as those of trachyte, but are much more extended. It also constitutes veins and penetrations between strata of stratified masses. Dome-shaped mountains or hills are of frequent occurrence, as also those which are truncated or actually conical. Basalt veins are of various thickness, and are frequently in such connexion with the caps, as to render it satisfactorily evident that the vein is simply the pipe or space through which the molten mass has been injected to cover the superior strata.

Basalts exhibit picturesque rock formation, especially when brought in contact with water, or where earlier cataclysms have given rise to valleys. This is the case on the Island of Staffa (*pl.* 52, *fig.* 6), on the Island of Tahiti (*pl.* 51, *fig*, 6), and in other places.

Basalt occurs under the most diversified forms, representing, in this respect, nearly all the rocks of which mention has already been made. Thus we may see the most beautifully regular columns of various lengths and diameter; globular and spheroidal formations are often combined with concentric shelly cleavage.

Basaltic amygdaloid is found on the exterior of the rocks in caps or veins, where bubbles of gas may distend the melted matter, leaving cavities on the cooling of the mass. These cavities subsequently became filled with the most beautiful crystallization. Small veins not unfrequently consist entirely of amygdaloid.

Basaltic masses are found as well on the bottom series as upon the newest tertiary; they traverse older plutonic, or other volcanoid rocks, as also ore

veins, although they themselves never contain these. Where basalts occur, they are generally combined with basalt conglomerate, which is often of great thickness. It generally lies at the foot, or on the slopes of basaltic mountains, and where it is tufaceous, it appears stratified, sometimes even alternating with strata of brown coal and woody opal. Where the basalt stands in contact with stratified rocks, the latter are influenced in the most varied manner, in a manner entirely attributable to the elevated temperature. Sand is converted into quartz grit, limestone into marble; silicious substances, as jasper, chalcedony, and hornstone, are forced into sandstone and lime, and partly melted together. Gypsum likewise is found in the vicinity of basalt.

A magnetic polarity has been ascertained to exist in basalt as well as in granite, dependent, in all probability, upon the magnetic oxyde of iron.

Basalt experiences a chemical decomposition, which is first indicated by a rusty coating to the surface. The soil resulting from such decomposition is often very fertile, and calculated to the formation of swamps.

Basalt is distributed in Greenland, Iceland, on the Faroes, in the Hebrides and in Ireland, also in Germany, France, Spain, Portugal, Italy, North Africa, America, on the South Sea Islands, and in the East Indies. In Germany it is seen on the Leine, on the Weser, in Hesse, in the Rhineland about Bonn and Coblentz, in Thuringia, in the Rhöngebirge, in Lausatia, Bohemia, Höhgau, &c.

3. Volcanic Rocks.

Volcanoes, among the most conspicuous of all geological phenomena, stand in the same relation to the other abnormal masses as the top rocks do to the normal or stratified; they come immediately after the volcanoid masses, from which, however, they are essentially different, although in many cases it is quite difficult to draw the line of distinction.

By volcanoes or burning mountains are generally to be understood conical elevations, with an apical concavity, in communication, by a deep hole or throat, with the interior of the earth, through which liquid masses and solid rocks are ejected from time to time. The concavity or crater, and the descending funnel, are characteristic of the volcano, although these features may be masked by the crumbling and falling in of the sides. *Pl.* 44, *fig.* 9, is a section of a volcanic cone. Volcanoes may be divided into two classes, active and extinct, with an intermediate form, the Solfatara, where there is a continued emission of sulphurous matters.

Active volcanoes have often long periods of rest or intermission, after which they again become active, and are so much the more devastating. An example of this is found in Vesuvius, whose eruptive history begins from the time of Pliny, and continues to the present time. Although there probably were eruptions anterior to the time of Pliny, yet of such we possess no record.

Extinct volcanoes are much more numerous than active; they occur in

many countries, and even in Germany in the Rhine region. The outbreaks of very many belong to ante-historical periods ; no doubt, however, can arise, as to their true character, as most still exhibit traces of former activity in the shape of lava currents, &c. These lava streams, in many cases, are exceedingly altered by the action of weathering and of water ; the craters, also, may either be in good preservation, or marked by the same atmospheric influences.

Pseudo-volcanic must be distinguished from truly volcanic phenomena. The two often exhibit great similarity, but are effects of different causes. Among these pseudo-volcanic exhibitions belong those terrestrial ignitions effected by the combustion of oxydizable substances in coal beds, such as are met with in various portions of England, Germany, and North America.

At Zwickau in Saxony, the ground is heated to such a degree, that all the conditions necessary to the existence of a hot-house are answered, by simply erecting an edifice on the heated portion. In these hot-houses, without additional artificial warmth, such tropical fruits as pine-apples, &c., may readily be reared. At Dudley, in England, the subterranean fire may be seen through fissures in the rocks in dark nights : smoke and vapors habitually rise out of these fissures, and are visible at all times, especially in wet weather. *Pl.* 52, *fig.* 4, represents the burning mountain near Duttweiler. A conspicuous illustration of the same phenomenon is exhibited in Schuylkill county, Pennsylvania, where the rubbish from an extensive coal mine became ignited, and finally the whole bed. The result of such combustion is naturally to effect transformations in the neighboring rocks, bearing a considerable resemblance to those produced by regular abnormal masses while incandescent. At Epterode, at the foot of the Meissner, in Hesse, there is a hill originally consisting of tertiary clay, which has been changed by the combustion of a coal bed into a slag-like compact rock, the so called porcelain jasper.

It was upon these subterranean combustions that Werner based his volcanic theory, which, however, meets with no support in the present state of science.

Volcanoes are found in all parts of the world, and are confined to no particular level. They sometimes crown the ridges of widely extended mountain chains, as on the South American Andes ; sometimes they rise up in mountainous or hilly regions and planes, and even from the bottom of the sea. The carefully conducted investigations of recent observers have shown that they are almost always in the neighborhood of the sea. Thus in Chili, in Peru, and in Mexico, they extend along the coast at no great distance ; in Europe, they lie along the Mediterranean Sea and the Atlantic Ocean. Most generally they occur on islands, many of which, unquestionably, owe their very origin to the elevation of the incumbent volcano. There are volcanoes, however, which lie entirely within the main land, among which may be mentioned the extinct cones in China, France, and on the Rhine. Still, we may readily reconcile this fact with the general law of the contiguity of volcanoes to the sea, by reflecting that the sea

level, as can be satisfactorily shown in some cases, might have been so different from what it is now, as even to have washed the very bases of the cones. *Pl.* 47, *fig.* 1, presents a comprehensive view of the volcanic regions of the globe; *fig.* 2 is a chart of European volcanoes, *fig.* 3, of those of lower Italy, all after Berghaus. On the latter, the earthquake region of Calabria and Sicily is indicated by the dark lines; that of Naples by a dotted outline. A fuller explanation of these charts will be found under the head of Physical Geography.

The shape of volcanoes is in general that of a more or less perfect, acute, or truncated cone. The ejected matters are heaped up around the mouth or crater. One of the most beautiful cones of this character is the Pic de Teyde on Teneriffe, as also Cotopaxi in the Andes chain. The height of volcanoes varies considerably, sometimes not reaching to the level of the sea, and at others extending into the higher regions of the atmosphere. Thus Stromboli, on the Lipari Islands, attains a height of 2,687 feet; Etna, of 10,814; the Peak of Teneriffe, 12,172; Mauna Roa, 13,760, and Mauna Koa, 13,953 (Sandwich Islands); Tunguragua in Quito, 16,424; Popocatepetl, 17,717, and Orizaba, 17,374 (Mexico); Cotopaxi, 18,890; Antisana, 19,150; Pinchincha, 15,940; Hecla, 3,324; Vesuvius, 3,978; Mount St. Elias, in North Western America, 16,775; Awatsha, in Kamschatka, 9,600. These heights are all above the level of the sea. The absolute height of the scoria about volcanoes naturally depends upon the number of eruptions. In Vesuvius they occupy $\frac{1}{3}$, in Pinchincha $\frac{1}{10}$, and in the Peak of Teneriffe $\frac{1}{22}$ of the entire cone. This part of the volcano, as forming the apex of the whole, naturally presents very steep sides of a mean inclination of 33° to 40°. The steepest parts of Vesuvius, of Jorullo, and of the Peak of Teneriffe, have an inclination of 40° to 42°.

The summit of the scoria cone is generally provided with a funnel-formed aperture, the crater. It is erroneous to suppose that the largest cones must necessarily have the largest craters; in fact, it would be more generally correct to say that the larger the cone the smaller the crater. The crater, generally circular, is of various diameters; that of Stromboli measures 50 feet, that of Vesuvius 1500 and over, of Etna 1250. The nearly elliptical crater of the Peak of Teneriffe has diameters of 200 and 300 feet, that of Popocatepetl 5000 and 4000. The largest known crater is that of Mauna Roa in the island of Hawaii; this is three and a half miles long, two and a half wide, and a thousand feet deep, large enough, in the language of Captain Wilkes, to accommodate the entire city of New York, leaving still an abundance of room.

The edge of the crater may also vary in character; it is generally, however, elevated like a wall, and descending nearly vertically towards the mouth (*pl.* 50, *fig.* 7, interior of the crater of Etna). It is often intersected by deep fissures, through which access may be had to the mouth. The depth of the crater of the Peak of Teneriffe amounts to 110–115 feet, that of Pinchincha to 1800, and that of Popocatepetl to 800–1000 feet.

The bottom of the crater is either simple or provided with various small cones of eruption, of which a greater or less number are in active operation.

The crater of Kirauea (*pl.* 47, *fig.* 4), on the island of Hawaii, with a depth of 1000 feet, and a circumference of eight miles, has fifty of such small cones of eruptions; a night scene in this crater is shown in *pl.* 49, *fig.* 1.

Similar phenomena are exhibited in the crater of a volcano on the island of Hawaii (*pl.* 47, *fig.* 5). Some volcanic cones are inclosed by a wall of gentle slope outside, but dipping abruptly towards the cone. Such is the Somma which surrounds Vesuvius, and is probably the wall of the ancient crater as it existed in the time of the Romans. *Pl.* 45, *fig.* 4, is a supposed view of Vesuvius in the time of Pliny: *fig.* 5, as seen at the present day.

The lava streams which accompany a volcanic eruption do not generally pour over the edge of the crater, but escape through fissures which may be formed in the sides. Among the most important volcanic products may be mentioned, lavas, pumice, various ejected matters, volcanic conglomerates, sublimates, and rocks altered by heat and vapors.

By the term *lava* is meant all volcanic matters exhibiting a liquid molten character. Lavas have a very different appearance under different circumstances; which difference, however, is rather accidental than essential. Even the same species of rock may exist under very different forms; thus pumice-stone is nothing else than trachyte in a frothy condition, and obsidian is the same, of a glassy and compact texture. Lavas may exist under the various forms of fillings, of strata, and as streams. The fillings generally occur in fissures through which an eruption has taken place, and present a striking resemblance to some of the veins we have already considered. Lava strata are pseudo-morphous, deriving their stratiform character by penetrating between true strata. This, however, is not always the case; it may happen that an earlier stream of lava, with the usual incumbent scoria and ashes, is covered by one of subsequent origin, and this, in like manner, by a third, &c., so that an alternation of stratiform masses of lavas and scoria may exist. The peculiarities of the masses are seen most conspicuously in the lava streams. These streams flow down the sides of the cone as far as the amount of the lava and the peculiarities of the soil may allow.

The greatest lava stream of Mount Vesuvius had a length of 47,500 feet. That which took place in 1805, was 16,735 feet long, with a breadth of 8,542, and depth of 30–40 feet.

Lava currents must naturally obey the laws which regulate other liquid masses. Should they meet with some obstruction in their course, such as a mountain or large rock, they divide into arms; flowing in a trough or channel they fill it up; pouring over precipitous descents, they form fiery cascades. They frequently run into the sea, and there sometimes form conspicuous features. Thus the lava stream which poured forth from Vesuvius, in 1794, ran into the sea, and formed a peninsula, eight hundred feet broad and seventeen feet high above the level of the sea. The surface of molten lavas soon cools, and forms a stiff crust beneath which the liquid mass still flows on. If this interior current be interrupted, it frequently breaks through the incumbent crust, and piles up on the surface, this

sometimes giving rise to lava arches such as are met with in Iceland (*pl.* 52, *fig.* 3). When the lava currents pour into lakes, they sometimes dry these up; an example of this is furnished by the volcano Krabla in Iceland, whose inner crater is represented in *pl.* 50, *fig.* 6. It first attracted attention by its mighty eruption, May 17, 1724. Among the phenomena of this eruption, which continued for six years, was the advance of a single lava stream to Lake My-vatn, a distance of nearly six miles, and drying it up almost entirely.

The cooled lava has generally a very rough surface, caused by superficial bubbles and scoria. The interior is either amorphous, or separated in tabular, columnar, or spheroidal form. The spheroidal state is frequently exhibited by obsidian, which occurs in great extent in Iceland. The bubbles or vesicular cavities which are seen in the outer portions of the current, and which are not rarely heaped up so as to form large masses of pumice, are ellipsoids of greater or less perfection, and with the longer axis parallel to the direction of the stream.

Lava presents itself in general under three forms; as glassy, as stony, and as crystalline. The glassy has arisen from a very rapid cooling, and is furthest removed from the crystalline. It has a highly conchoidal and sharp-edged fracture, is brittle, more or less transparent, and of a vitreous lustre. Stony lava has a strong resemblance to stone ware; it is of earthy dull fracture, generally entirely opake, and intermediate between glassy and crystalline lava.

Lava streams may be referred to three classes: trachytic, basaltic, and leucitophyric. Trachyte lavas are characterized by feldspar or its minerals, which, however, is only recognisable when the aggregation state of the rock is decidedly crystalline. Crystalline trachytic lava forms a true trachyte, which generally is of a light color, not seldom modified by the presence of hornblende, specular iron, micaceous iron, and true brown mica. It frequently passes into porphyritic, so as sometimes to constitute a trachyte porphyry. The stony trachytic lava is often granulated, and contains vesicles and particles of glassy feldspar. The glassy is formed by pumices and obsidian; it is either pure, or contains porphyritically separated particles of feldspar.

Augite predominates in basaltic lava, accompanied by labradorite and various ferruginous minerals, for which reason these rocks are generally of a dark color. They are very similar to the true volcanic basalt, often so much so as to present no difference in petrographical character, this difference being only deducible from oreographical peculiarities. A true obsidian and pumice do not occur among the basaltic lavas, and a few glassy varieties of some similarity to these, are distinguishable by the simple blowpipe test that the former yield white, the latter dark globules on fusion. The crystalline granular basaltic lava exhibits a true dolerite, and for this reason is sometimes called dolerite lava: it characterizes Etna in particular. The stony lava is of a greyish black and brown color, with a compact vesicular, or slaggy interior. Here belong the Mühlstein of Niedermennig, not far from the Laacher Lake, as well as some basaltic lavas of Auvergne.

Leucitophyr lava consists of a combination of augite with leucite, in which sometimes one substance prevails and sometimes another. It is the same leucitophyr whose petrographical character we have already become acquainted with. It likewise embraces many other minerals which are not essential to its composition, as zeolite, sodalite, mica, micaceous iron, nepheline, harmotome, &c.; it occurs both crystalline and stony. The crystalline leucitophyr often contains perfect crystals (trapezohedra), whose tolerably equal dimensions and light color contrast remarkably with the black prisms of the augite.

The term "volcanic ejectamenta" includes everything thrown into the air by volcanic forces. They are of very different character, and vary not only in different volcanoes but in different eruptions of the same volcano. Under this head belong pieces of lava torn off from the interior of the throat or mouth of the volcano, and hurled out during the eruption; also, the so-called bombs or spheroidal lava masses, which, ejected into the air, have had a rotary motion communicated to them, and cool before reaching the ground. The form of these bombs is that of elliptical spheroids elevated at the equator and flattened at the poles, presenting a miniature resemblance to the terrestrial globe. Additional substances thrown out of the volcano are lava gravel; volcanic sand, consisting of crystalline particles of volcanic minerals; volcanic ashes, consisting of the dust of ground up rocks; volcanic threads produced from the lava like fine fibres from molten glass; finally, blocks of foreign rock species, as granite, gneiss, mica slate, dolomite, sandstone, and limestone, the latter, when inclosed by the lava, being partially or entirely converted into marble. These ejectamenta, after being deposited in an appropriate location, are frequently so acted upon by water as to become converted into volcanic conglomerate and volcanic tufa. They then appear stratified, and are distinguished according to the character of their components into trachyte conglomerate, trachyte tufa, basalt conglomerate, leucitophyr, conglomerate, and leucitophyr tufa; these, not unfrequently, are broken up into conspicuous rocks by subsequent convulsions, and are sometimes traversed by veins of lava.

Volcanic mud is produced by the union of volcanic ashes or dust with water, which, vaporiform while escaping from the mouth of the volcano, becomes condensed in the higher regions of the atmosphere, and descends in the form of rain, accompanied by thunder and lightning. Currents are sometimes produced under such circumstances, sufficient to devastate extended regions. These muddy waters not unfrequently accumulate in subterranean cavities; and by means of fissures in the sides of the mountains, are allowed to escape into the lower lands. According to Humboldt, discharges of mud never take place in the same manner as lava. The subterranean lakes sometimes contain a great number of fish, which are discharged with the water in which they live. These fish are, however, not peculiar to the subterranean waters, being found in the superficial lakes and streams. Thus *Arges cyclopum*, Val. (*Pimelodus cyclopum*, Humb.), and *Brontes prenadilla*, Val., are emitted from the volcanoes of Tunguaragua and Cotopaxi in South America.

Volcanic sublimates are not only of great extent, but are often of great importance to mineralogists. These are bodies which continue in the form of vapor until condensed into the solid state by cooling, in which case they generally coat the walls of the crater and the cavities in the lava with a crystallization of greater or less perfection. Volcanic sublimations are met with not only in active volcanoes, but also in such as are nearly extinct, or the *Solfataras*. The principal sublimates are, combinations of chlorine, sulphur and sulphuric acid combinations, and metallic oxydes.

The gaseous exhalations and deposits from volcanic waters stand in intimate connexion with these sublimates. Among the gases are carbonic acid, sulphurous acid, and chloride of hydrogen or hydrochloric acid. Sulphites are formed by the action of the sulphurous acid upon the neighboring rocks, which by further oxydation, are converted into sulphates. In this manner are formed sulphate of ammonia, sulphate of soda (glauber salts), sulphate of alumina, sulphate of iron, alum, and alum stone. The deposits from volcanic waters consist generally of silicious sinter, more rarely of borax. Naphtha springs appear likewise to stand in a certain connexion with volcanoes.

Besides the primary phenomena of volcanoes, as lava currents and ejectamenta, there are others of secondary or derivative character, as earthquakes. A striking feature presented to us in our examination of a volcano mountain, is the great homogeneity of its character; furthermore, that its shape is almost always conical, with a crater upon the summit, and the entire mass different in petrographical character from the region above which it projects. All these circumstances, with the fact that no crater is found upon the summit of a mountain not volcanic, clearly evince that an exceedingly intimate connexion must exist between the formation of the crater with its central throat and that of the mountain itself. The mountain in which the crater is situated must first have originated by volcanic upheaving; eruptions then followed, whose ejecta accumulated and gradually increased the size of the cone. After this heaping up around the mouth of the volcano had increased to a certain amount, the internal forces were no longer capable of raising the volcanic matters to the level of the mouth; fissures were then formed in the sides of the mountain, through which the lava was emitted. These phenomena are met with in the highest volcanoes. The formation of volcanic mountains has indeed been actually observed; striking instances of which are exhibited in the case of Monte-Nuovo near Naples, of Jorullo in Mexico, and of various volcanic islands elevated in the sea.

The formation of Monte-Nuovo took place in September of 1538. (See the chart of the Bay of Naples and its volcanic district, *pl.* 45, *fig.* 8.) It rose up from a plain of inconsiderable elevation above the level of the sea, after premonitory quakings of the earth of two years' duration. On the 28th of September flames burst forth from the earth, the ground cracked open, and a considerable quantity of water escaped, while the sea retreated about three hundred paces. On the following day, soon after the sun of a fiery red had set behind the western waters, a cavity opened near the sea,

which vomited forth flame, smoke, dust, and pumice, which, in the course of two days, heaped up a mountain of about 8000 feet in circumference, and of considerable height, with a crater on the summit. Shortly afterwards, this outbreak ceased, and the whole became quiet. Subsequently followed other powerful eruptions, but at the present time, Monte-Nuovo belongs to extinct volcanoes, overgrown with the most luxuriant vegetation, and whose crater exhibits only traces of its original condition.

The elevation of Jorullo in Mexico, as described by Alexander von Humboldt, must have been an awfully sublime spectacle. The locality of this stupendous exhibition was a highly cultivated plan, elevated about 2000 feet above the level of the sea, with loosely scattered blocks of basalt upon the surface. In June of 1759, a terrible bellowing was heard, with ominous earthquake shocks. This lasted sixty days, until, towards the end of September, all danger appeared to have vanished. But suddenly, in the night of the 18th and 19th of this month, the sounds recommenced, and an extent of land of nearly four square miles was covered with scoria and lava, by means of eruptions, which did not cease until February, 1760. Six volcanic cones were formed, the central one, or Jorullo, attaining an elevation of 1600 feet above the level of the plain. Thousands of small cones, called hornitos, are dotted over the region, produced by the heaping up of dome-shaped masses of lava by the disengagement of gaseous matters. Some have supposed that part, at least, of the general elevation has been produced by the actual elevation of the plain, as on the surface of a gigantic bubble; this hypothesis, however, hardly appears to be substantiated by the physical features of the region. The six cones above referred to, were arranged along an immense fissure, extending from north-east to south-west. From this central fissure, with its subsequent ridge and six elevations, the volcanic masses slope at a general angle of 6° to the circumference of the tract. It is not probable that any material accession to the volcanic matter was experienced after the year 1760; at the present day, the greater portion of the plain is covered with a rich growth.

The elevation and disappearance of the island of Ferdinandea in the channel between Sicily and Africa, was a highly interesting phenomenon. The water of the sea was thrown into great waves, gigantic columns of smoke escaped, the neighboring coasts experienced earthquake shocks, and an island rose suddenly from the troubled sea. It was on the 28th of June, 1831, that earthquakes were experienced in Sciacca, on the southern coast of Sicily, accompanied by a thundering noise. A British vessel in the vicinity experienced shocks, and vesicular dust was carried by the winds and deposited on the Sicilian coast. At break of day, on the 13th of July, up to which time the indications of volcanic phenomena were continued, the new volcano was first observed from Sciacca, emitting immense volumes of sulphurous acid, which annoyed the whole neighboring region. A few days after, an immense expanding column was observed to rise out of the mouth of the volcano, consisting of various ejecta, the more solid portions of which fell into the water with a hissing sound. Lightnings, accompanied by heavy thunder, illuminated the dark scene, whose horrors were heightened by

subterranean explosions. On the 28th of September, when the mouth had ceased to emit anything except sulphurous vapors, Prevost, in company with some fellow-voyagers, visited the island, and remained upon it for several hours. He ascertained the circumference to amount to 2000 feet, and the highest point of the crater to extend to an elevation of 200 feet above the level of the sea. The lake which filled the crater, and which stood at the same level with the ocean, was about about 180 feet in diameter. *Pl.* 50, *fig.* 4, presents a view of the island, and *fig.* 5 one of the inner crater. The island subsequently began to sink, standing at the level of the sea at the end of September, until at the beginning of December it had entirely disappeared. Quite similar circumstances attended the elevation of a small volcanic island, in 1811, near St. Michael, one of the Azores; it disappeared subsequently, so that now there is a depth of eighty fathoms and more over the summit. A figure of the island, at the time of its elevation, is presented in *pl.* 50, *fig.* 2.

After the lightnings which accompany an eruption, and the subterranean explosions, have ceased to excite terror and apprehension in the hearts of the beholders, there sometimes arise luminous columns of fire, veiled in a black vapor. Nature appears then for a moment to be appeased and at rest: but new volcanic agencies commence which may be far more dangerous than any which have preceded. These are the mofettes, or gas springs, which, emitting noxious gases, such as carbonic acid, diffuse deadly poison throughout the entire region. While many of these soon disappear, others remain permanent for a long time, as the Grotto del Cane, near Naples (*pl.* 51, *fig.* 7), or else exist as acid springs in combination with water.

Earthquakes generally announce an eruption; they are movements of the solid crust of the earth, whose cause or origin lies concealed within her bowels. A precise connexion between the two series of phenomena may not be strictly established, although such relation can in many cases be substantiated. The motions of the earth which constitute an earthquake are either horizontal and vertical, or rotatory: they are greatest in the centre of the field of influence, decreasing gradually to its borders. The extent of surface affected in a single system of earthquake is very various, and sometimes of great amount; in the earthquake of Lisbon it covered the half of Europe, and as far as the West Indies. Deep fissures are often formed by earthquakes, such as those near Polistena in Calabria (*pl.* 44, *fig.* 15), and sometimes circular cavities, as in the plain of Rosarno (*fig.* 16), produced by the earthquake of 1783.

The greater number of hot springs belong to volcanic exhibitions, as is well shown by their occurrence, in most cases, in volcanic regions. The most striking of these phenomena is to be found in the case of the Geyser of Iceland (*pl.* 50, *fig.* 1), a periodical spring, whose waters at a boiling heat are ejected to a considerable height in the air. The opening of the spring, or of the crater, lies on a hill consisting of silicious sinter, which the water had previously contained in the form of soluble silex. This action is shown in *pl.* 44, *fig.* 17. Iceland is especially rich in other volcanic phenomena of extraordinary grandeur. *Pl.* 45, *fig.* 10, is a chart repre-

senting the Iceland volcanic region. In the south of Iceland is the high cone of Hecla, and the snow and ice-covered volcano of Eyafiël. Of this volcano as of the island of Westmann, in front of it, a view is presented in *pl.* 44, *fig.* 18. They lie on the southern exit of a wide valley, which is continued between trachytic masses. Northwardly this valley runs towards a group of volcanoes constituted by Krabla, Leirhnukur, and others, while the elevated Oräfejökul to the east rears its proud head towards the sky.

A phenomenon, sometimes called an aerial volcano, is not unfrequently found to accompany earthquakes. This is constituted by a small cone of eruption, consisting of accumulated mud masses, often impregnated with saline waters. From the mouth is emitted gaseous matter, generally hydrogen, which is alternately inflamed and extinguished. The air volcanoes of Turbaco in Columbia (*pl.* 50, *fig.* 3), are very conspicuous in this respect.

Leopold von Buch makes a distinction between volcanic centres and volcanic lines. The first kind consist of a central volcano surrounded hy several smaller ones, which are pretty equally distributed in every direction. Mount Etna, in Sicily, is a central volcano, with its smaller cones of eruption arranged about its base. In the view of Etna on *pl.* 45, *fig.* 6, *a*, indicates Montagnuola; *b*, Torre del Filosofo; *c*, the highest point of the mountain; *d*, Lepra; *e*, Finocchio; *f*, Capra; *g*, the cone of 1811; *h*, the Cima del Asino; *i*, Musara; *k*, Zoccolara; *l*, Rocca de Calanna. On the volcanic chart of the same region (*fig.* 9), 1 indicates the volcanic formation, 2 the newer pliocene, and 3 the latter formation combined with the former. *Fig.* 7 represents the Campi Phlegræi; *a*, Montenuovo; *b*, Monte Barbaro; *c*, Solfatara; *d*, Lake Lucrine; *e*, Lake Averno; *f*, the city of Pozzuoli; and *g*, the tongue of land Baja.

Linear volcanic series are seen in high development on the elevated crest of the Cordilleras de los Andes, extending over a line of many hundred miles, with individulal cones succeeding each other at greater or less intervals.

Various hypotheses with regard to volcanoes have been propounded by the earlier geologists, few of which are now considered to exhibit any show of probability. One of the least objectionable of modern theories is that of Housmann, who considers lavas to be nothing else than products of oxydation of bodies previously unoxydized, which exist at the confines between the molten nucleus of the earth and the hard crust. That the interior of the earth must consist of denser masses than the exterior, is sufficiently evinced by the fact, that the mean density of the entire earth amounts to 4.70 (5.50 according to Cavendish), and that of the outer crust to but 3.00. When these unoxydized bodies, which consist principally of potassium, sodium, aluminum, silicon, iron, &c., come into contact with water, this is decomposed, and oxydes are formed with the evolution of great quantities of heat and hydrogen; the latter, mixed with oxygen of the air, produces the explosions. The sea-water penetrating at a great depth, appears to be the principal source of the water required; a fact well illustrated, by the situation of volcanoes within a moderate distance of

the sea, and confirmed by the occurrence of chlorine combinations, of nitrogenous substances and bitumen. The steam may be produced from the water existing in the abyss, and also by the re-combination of hydrogen and oxygen of the atmosphere. The oxydes thus produced are melted together in the hearth of the gigantic furnace by means of heat derived from the central fires, as also from the oxydation itself, and in the form of lavas are vomited up over the blooming fields, carrying death and destruction in their path.

V. THE SURFACE OF THE EARTH IN GENERAL.

In considering the external form of the earth, and of the relations between normal and abnormal masses, we have seen brought in review before us mountains and valleys, land and water. The mountain is seen to be nothing else than a slight elevation above the general level, and the watery surface only a filling up of a depression. Yet, however fortuitous all these features may appear to be, an attentive observation reveals to us the existence of certain laws influencing the general result.

The elevations in the form of mountain chains contribute very essentially to the character of our globe. These had certainly never arisen but for the longitudinal disturbance by plutonic masses of the original horizontal position of the rock strata. The position of the strata thus appears to be dependent upon plutonic masses, as may be observed in almost all mountain chains: the cases are indeed rare where this conclusion is unsupported by actual exhibition of these masses themselves. Even if certain changes are not attributable to such masses, they may belong to some of their concomitants, such as the vapors produced in the interior of the earth. *Pl.* 47, *fig.* 7, presents a comparative view of the principal mountain heights of the old world; *fig.* 8 does the same for the new.

Volcanoid and volcanic masses are of much less importance in influencing the general shape of the earth; they only form domes, single mountains and hills, upon localities furnished to them by plutonic rocks.

It is exceedingly difficult, if not absolutely impossible, to picture to our minds the condition of the earth at its first period of development. Speculative geology or geogeny may indeed endeavor to penetrate to the bottom of all the phenomena and facts which are furnisbed to it by geognosy as a purely empirical science: it may seek to develope the causes which have produced such mighty effects, and thus pass itself step by step to the primeval condition of our planet, to speculative hypotheses as to its original shape, to the laws according to which its fashioning proceeded, to the causes upon which depended the successive changes on its surface. And these speculations may not be disregarded, but their application must be made with all due caution, that the proper and legitimate bounds of reasoning be not overstepped. According to Laplace, the earth, with the entire solar system, at one time, was a vastly diffused nebulous mass, set in rotary

motion, and, by successive subdivisions, furnishing the material for the individual bodies of our planetary world. These masses of vapor must have possessed a temperature sufficient to retain all the solid components in the gaseous condition. Such is the hypothesis of astronomy; geology takes it up at the time when the vapor is supposed condensed into a liquid, still molten mass, to which an ellipsoidal shape is given by a rapid rotation about an axis. In cooling, the earth becomes invested by a solid crust, upon which the aqueous vapors of the atmosphere are condensed. In proportion as the nucleus of the earth parts with its heat by radiation into space, must contractions of its volume take place; and the space between the inner kernel and the outer shell being thus of considerable amount, the incumbent mass breaks in and permits the access of atmospheric air to the fires below. The effects exhibit themselves in volcanic reaction, by means of which certain portions of land become elevated above the general level. A repetition of such depressions and elevations results in the elevation of entire continents with their mountain ranges and the collection of the great body of water in the interspaces. The ascending vapors from this water become condensed to clouds, fall in the form of rain, and, after partially saturating the more elevated regions, burst out into springs, whose combination produces rivers and lakes, all emptying continually into the great body of ocean, by a more or less circuitous course. The sea, as well as the fresh water, acting on these continents, exerts a destructive influence upon the harder portions; and the finer particles resulting from their action are spread out and deposited as strata in some quiet bay or lake. Smaller fragments, subdivided by concussion, attrition, atmospheric agencies, or other causes, are also carried down to form conglomerates. The masses arranged thus horizontally, and hardening by the incumbent weight or other influences into solid rocks, are elevated afresh, and new lines of demarcation are drawn between the waters and the dry land. We may safely consider such operations of aqueous and igneous causes as sufficiently capable of producing all the geological features of our globe.

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